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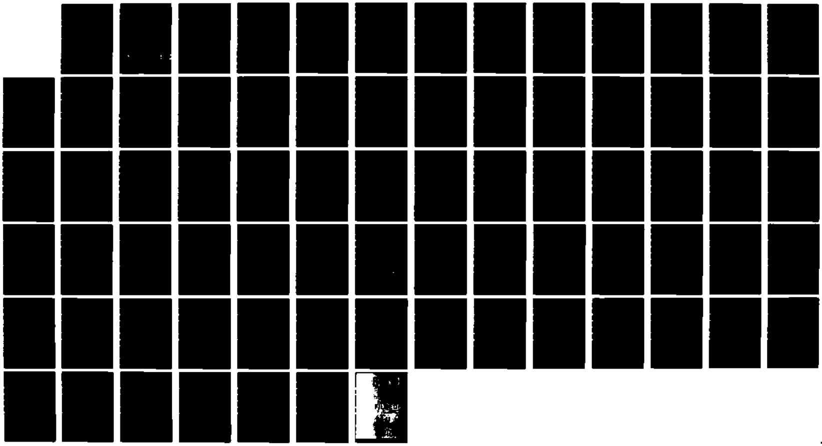

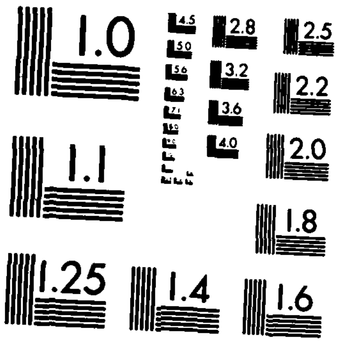

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NUSC Technical Report 6879
21 March 1983

ELF PVS Field Strength Measurements, January 1977

Peter R. Bannister
Submarine Electromagnetic Systems Department

Naval Underwater Systems Center
Newport, Rhode Island/New London, Connecticut

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Preface

This report was prepared under NUSC Project No. A59007, "ELF Propagation RDT&E" (U), Principal Investigator, P.R. Bannister (Code 3411). Navy Program Element No. 11401N and Project No. X0792-SB, Naval Electronic Systems Command Communications Systems Project Office, D. Dyson (Code PME 110), Program Manager ELF Communications, Dr. B. Kruger (Code PME 110-XI).

The analysis and write up of this report was performed while the author was occupying the Research Chair in Applied Physics at the Naval Postgraduate School, Monterey, CA. The author would especially like to thank Professors Otto Heinz and John Dyer and Dean Bill Tolles for recommending him to occupy this post and NAVSEA (Code 63R) for sponsoring the Chair.

The Technical Reviewer for this report was Raymond F. Ingram.

Reviewed and Approved: 21 March 1983

D. F. Dence
Head, Submarine Electromagnetic Systems Department

The author of this report is located at the
New London Laboratory, Naval Underwater Systems Center,
New London, Connecticut 06320.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

From September 1976 to December 1978, extremely low frequency (ELF) field-strength and effective-noise measurements were taken aboard operational submarines. The results of measurements taken aboard three different submarines during January 1977 are discussed in this report. The principal result is that the average measured field-strength and relative-phase values are in excellent agreement with the predicted values that are based on simultaneous measurements taken in Connecticut.

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GLOSSARY OF ABBREVIATIONS

ELF	Extremely low frequency
EW	East-west
GMT	Greenwich Mean Time
MSK	Minimum shift keying
NS	North-south
NUSC	Naval Underwater Systems Center
PVS	Propagation validation system
SNR	Signal-to-noise ratio
SRTP	Sunrise transition period
SSTP	Sunset transition period
STIU	Signal timing and interface unit
TTY	Teletype
WTF	Wisconsin Test Facility

ELF PVS FIELD STRENGTH MEASUREMENTS, JANUARY 1977

INTRODUCTION

The ELF* propagation validation system (PVS) is composed of the U. S. Navy's extremely low frequency (ELF) Wisconsin Test Facility (WTF) and ELF receivers (AN/BSR-1) installed on submarines and at certain land sites. The WTF is located in the Chequamegon National Forest in north-central Wisconsin, about 8 km south of the village of Clam Lake. It consists of two 22.5 km antennas; one antenna is located in approximately the north-south (NS) direction and one is located in approximately the east-west (EW) direction. Each antenna is grounded at both ends. At 76 Hz, the electrical axis of the NS antenna is 14 deg east of north, while the electrical axis of the EW antenna is 114 deg east of north.[1] The WTF antenna array can be steered electrically toward any particular location and its radiated power is approximately 1 W.

The AN/BSR-1 receiver is composed of an AN/UYK-20 minicomputer, a signal timing and interface unit (STIU), a rubidium frequency time standard, two magnetic-tape recorders, and a preamplifier. The message output is on a teletype (TTY), which is used to control the receiver. The submarine receiving antenna is a buoyant cable 1.6 cm in diameter with electrodes spaced 300 m apart on a 580-m transmission line.

The system uses minimum shift keying (MSK) modulation with a center frequency of 76 Hz. The signalling scheme uses block orthogonal coding to make maximum use of the limited transmitter power available. This scheme provides the most efficient use of the transmitter for short messages.

During January 1977, three submarines involved in testing were located in the North-Atlantic/Norwegian-Sea area at a range of approximately 5 Mm from WTF. Signal-strength data (both amplitude and relative phase) were recorded automatically by each submarine whenever the ELF receiving antenna was streamed, though no special operational posture was adopted to provide ELF reception.

Regarding the submarine data, the depth and orientation are automatically accounted for by the receiver. The submarine data analyzed in this report have been taken at essentially constant depth and orientation for considerable periods of time. We also have a substantial amount of unreduced (as far as signal amplitude and phase are concerned) submarine data where the speed, depth, and orientation of the submarine were varying considerably. These particular data are not too useful for obtaining accurate signal amplitude and phase information. However, they are very useful for obtaining information on messages received during submarine maneuvers.

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*ELF (formerly called SANGUINE/SEAFARER) is an arbitrary designation applied to ongoing extremely low frequency research by the U. S. Navy. The term designates work directed toward the implementation of an ELF shore-to-ship radio communication system.

In this report, we will discuss the results of these January 1977 submarine field-strength measurements and will compare them with simultaneous measurements taken in Connecticut.

JANUARY 1977 RESULTS

During January 1977, data were obtained from submarine 1 on 8 days (1/2 to 1/9), from submarine 2 on 6 days (12/31 to 1/5), and from submarine 3 on 19 days (1/1 to 1/10 and 1/16 to 1/26). At the Connecticut site, data were obtained on 28 days.

The WTF transmitted 76-Hz modulated signals from 0000 to 1800 Greenwich Mean Time (GMT) during 1 to 10 January and 0600 to 2200 during 16 to 26 January. The WTF antenna phasing was 21 deg during both periods.

The average effective-noise (N_{eff}) values measured on all three submarines is plotted in figure 1* versus GMT. Previous January effective-noise measurements in the Norwegian-Sea area (Tromso, Norway) indicated that the median value was -148 to -150 dBH (where dBH = dBA/m$\cdot\sqrt{1\text{ Hz}}$), with a diurnal variation of 6 to 8 dB.[2,3] The minimum effective-noise values occurred in the early morning (around 0400 to 0800 GMT), while the maximum values occurred in the late afternoon or evening (around 1400 to 1800 GMT).

Referring to figure 1, we see that the effective-noise values measured on all three submarines was too high (by 5 to 10 dB) and exhibited little diurnal variation (2 to 3 dB). Thus, it appears that the effective noise measured on all three submarines was contaminated by submarine-generated noise (external or internal to the submarine).

Despite the high values of effective noise, useful signal data (both amplitude and relative phase) were obtained from all three submarines. The average predetection (in a 1-Hz bandwidth) signal-to-noise ratio (SNR) at optimum heading was approximately -7 dB on submarines 1 and 2 and approximately -10 dB on submarine 3. The average postdetection (after 30-min integration time) was approximately 25.5 dB on submarines 1 and 2 and approximately 22.5 dB on submarine 3.

The submarine daily field-strength averages for the first 10 days in January are given in table 1, while the 16 to 26 January submarine 3 daily field-strength averages are given in table 2. The data in each table are broken up into three time periods which should be representative of

1. All night-propagation conditions (~0000 to 0800 GMT),

2. Transition-period propagation conditions (~0800 to 1400 GMT and 1800 to 2400 GMT), and

3. Daytime-propagation conditions (~1400 to 1800 GMT).

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*Figures have been placed together at the end of this report or in the applicable appendix.

Table 1. Submarine Daily Field-Strength Averages for the First 10 Days in January 1977

Date	Night (0000-0800) (dBA/m)	Transition (0800-1400) (dBA/m)	Day (1400-1800) (dBA/m)	$\Delta\phi$ (deg)
Submarine 1:				
1/1/77	-	-	-	-
1/2/77	-	-	-149.8	-
1/3/77	-150.1	-149.3	-150.0	55
1/4/77	-149.8	-149.6	-149.6	76
1/5/77	-	-	-152.0	-
1/6/77	-152.1	-152.0	-152.1	66
1/7/77	-151.1	-150.2	-149.9	82
1/8/77	-150.8	-150.4	-151.2	72
1/9/77	-150.7	-152.2	-151.2	93
1/10/77	-	-	-	-
Average	-150.7	-150.5	-150.6	74
Submarine 2:				
12/31/76	-152.9	-151.9	-150.4	50
1/1/77	-153.7	-150.9	-151.3	23
1/2/77	-153.1	-150.7	-149.8	47
1/3/77	-154.2	-151.7	-149.8	32
1/4/77	-151.2	-150.5	-148.6	48
1/5/77	-152.7	-152.1	-151.4	51
Average	-152.8	-151.3	-150.2	42

Table 1. (Cont'd) Submarine Daily Field-Strength Averages for the First 10 Days in January 1977

Date	Night (0000-0800) (dBA/m)	Transition (0800-1400) (dBA/m)	Day (1400-1800) (dBA/m)	$\Delta\phi$ (deg)
Submarine 3:				
1/1/77	-153.8	-151.2	-	-
1/2/77	-153.5	-152.4	-1[illegible]0	43
1/3/77	-156.8	-152.0	-[illegible]6	23
1/4/77	-	-	-1[illegible]2	52
1/5/77	-152.6	-151.5	-1[illegible]	57
1/6/77	-149.7	-150.4	-148.1	66
1/7/77	-150.2	-149.3	-149.4	49
1/8/77	-150.9	-150.7	-149.3	35
1/9/77	-148.9	-149.9	-151.6	67
1/10/77	-151.0	-152.0	-150.7	60
Average	-151.6	-150.9	-149.8	50

Referring to tables 1 and 2, we see that there is a considerable day-to-day variation in the received field strengths (both in amplitude and relative phase). That is, the average field strength sometimes changes by 2 to 4 dB from one day to the next, while the average relative phase changes by 15 to 30 deg. This phenomenon is typical of ELF auroral zone propagation.[4,5]

The average January field-strength and relative-phase values are plotted in figures 2 through 4 versus GMT, while the 2 to 9 January submarine 1 averages are compared with the 16 to 26 January submarine 3 averages in figure 5. Note that the average field strengths measured on these two submarines during different time periods (figure 5) were almost duplicates of each other, in both amplitude and relative phase.

During the WTF daytime period of 1400 to 1800 GMT, the average field strengths essentially were constant and about the same magnitude (-150.2 ±0.4 dBA/m) for all three submarines.

Table 2. Submarine 3 Daily Field-Strength Averages, 16 to 26 January 1977

Date	Night (0600-0800) (dBA/m)	Transition (0800-1400) (dBA/m)	Day (1400-1800) (dBA/m)	Transition (1800-2200) (dBA/m)	$\Delta\phi$ (deg)
1/16/77	-	-	-	-150.7	-
1/17/77	-150.5	-150.5	-150.0	-151.5	58
1/18/77	-151.9	-150.5	-147.5	-150.5	54
1/19/77	-152.4	-149.5	-151.0	-150.6	69
1/20/77	-151.0	-149.8	-149.2	-150.7	72
1/22/77	-150.5	-151.1	-149.6	-150.0	58
1/23/77	-149.8	-148.8	-152.2	-149.7	73
1/25/77	-	-150.7	-149.3	-147.8	-
1/26/77	-152.4	-155.2	-150.3	-150.1	72
Average	-151.1	-150.5	-149.8	-150.0	65

During the transition period (0800 to 1400 GMT), the averages were approximately the same (-150.9 ±0.4 dBA/m), but the field strengths were not constant. The data from both submarines 1 and 3 exhibited amplitude dips around 1100 to 1200 GMT.

From our past measurements,[6-16] we know that ELF nighttime propagation is much more variable than ELF daytime propagation. This is also shown by the data presented in this report. The average nighttime field strengths (0000 to 0800 GMT) measured on all three submarines showed greater than 2 dB differences, with the highest (-150.6 dBA/m) measured on submarine 1 and the lowest (-152.8 dBA/m) measured on submarine 2. The data taken on all three submarines exhibited amplitude reductions around 0400 to 0800 GMT.

As a further example of the variability of ELF nighttime propagation, figure 6 is a comparison of the 3 January data taken aboard all three submarines with the data taken in Connecticut. Here, we see that, from 0000 to approximately 0400, the nighttime field strengths were fairly constant at all four receiving locations. However, the field strengths measured on the three submarines were substantially different. The average field strength measured during the 0000 to 0400 nighttime period was ~-150 dBA/m on submarine 1, ~-154 dBA/m on submarine 2, and ~-157 dBA/m on submarine 3, a 7-dB difference! From 0500 to 1800, the data from submarines 2 and 3 tracked very well, while during the WTF daytime period (1400 to 1800), the data taken aboard all three

submarines were quite similar. Referring to table 1, we see also that the 3 January average relative phase was 15 to 30 deg less than that measured on the preceding and succeeding dates, which is indicative of a change in the reflection height at the submarine receiving sites. This change is probably due to particle bombardment during the 29 December 1976 magnetic-storm recovery period. Another possible explanation for these anomalous nighttime submarine results (figure 6) is that the receivers are on great-circle paths that are nearly tangential to the disturbed polar cap, in which shadow zones and interference patterns could occur.[17]

There were other times when the data taken aboard different submarines tracked very well. The 5 January data taken in Connecticut and aboard submarines 2 and 3 are plotted in figure 7; the 8 January data taken in Connecticut and aboard submarines 1 and 3 are presented in figure 8. On 5 January (figure 7), the data from all three sites were very similar, with amplitude dips around 0500 to 0600 and 1100 to 1300. On 8 January (figure 8), the data taken aboard the two submarines tracked very well and exhibited the same general behavior as did the Connecticut data (except for the 1600 to 1800 period).

Further examples of ELF short-term variations are presented in figure 9, which compares data taken in Connecticut with data taken aboard submarines 1 and 3. On 6 January, from 0200 to 0530, the field strengths on submarines 1 and 3 were ~4 dB different in magnitude. However, from 0600 to 1000 the data from all three locations tracked very well, with peak-to-trough variations of 3 to 4 dB. The 0600 to 1000 field-strength variations are probably due to changes in excitation factor at WTF or along the whole path.

On 19, 20, and 23 January (figure 9), there were abrupt increases in the received field strengths at both the Connecticut and submarine 3 receiving locations. Here, again, these short-term variations probably were caused by changes in the excitation factor at the transmitter or along the whole path.

The Connecticut and submarine 3 data for 25 and 26 January are presented in figure 10. The Connecticut data showed a gradual increase (2 to 3 dB) in the received field strength from nighttime to daytime propagation conditions. However, from 1800 to 2200 on 25 January the submarine 3 data were ~2 dB higher than the 16 to 26 January average, while from 0800 to 1400 on 26 January the submarine 3 field strengths were ~5 dB lower than the 16 to 26 January average field strength. These field-strength variations are due to localized ELF propagation-condition changes near the submarine receiving area, rather than to transmitter or total-path excitation-factor variations.

DATA INTERPRETATION

For distances sufficiently removed from the region of the antipode, the farfield horizontal magnetic field-strength component (H_ϕ) produced by the WTF array (normalized with respect to the EW antenna at a current of 300 A) may be expressed as[6,7,18]

$$20 \log H_\phi \sim K + 20 \log E - \alpha\rho - 10 \log (\alpha \sin \rho/\alpha) + 20 \log \frac{F(\phi)}{B} \text{ dBA/m} , \quad (1)$$

where

K = 139.1 dB at 76 ...,

$E = \left(h_{KM}\sqrt{\sigma_{EW}}\sqrt{c/v}\right)^{-1}$ is defined as the earth-ionosphere waveguide excitation factor (note that E is inversely proportional to the product of the effective ionospheric reflecting height h (in km) times $\sqrt{\sigma_{EW}}$,

σ_{EW} = effective earth conductivity beneath the WTF EW antenna = 3.2 × 10^{-4} mho/m at 76 Hz,[18]

c/v = ratio of free space to earth-ionosphere waveguide phase velocity,

α = earth-ionosphere waveguide attenuation rate (dB/Mm),

ρ = great-circle distance between WTF and receiver (Mm),

a = radius of the earth (~6.37 Mm), and

$F(\phi)/B$ = WTF array pattern factor, which equals unity in the direction of the EW antenna axis.[1]

From equation (1), we see that for a two-site measurement program the only unknowns to be determined are α and E, assuming that the excitation factor is the same at both receiving sites. We have also shown[7] that α is directly proportional to E. That is, at 76 Hz, $\alpha \sim 1.4E$ dB/Mm. Since α is directly proportional to E, field-strength measurements could be taken at just one site to obtain <u>average</u> values of α and E for a particular measurement period.

The average amplitude and relative-phase data taken in Connecticut during 2 to 10 January and 17 to 26 January are plotted versus GMT in figure 11. Note that, during the two measurement periods, the Connecticut amplitude and relative-phase data were almost mirror images of each other.

From the Connecticut January measurements, the average nighttime α was determined to be ~0.9 dB/Mm, while the average daytime α was determined to be ~1.25 dB/Mm. The average relative-phase velocity difference between daytime and nighttime propagation conditions [$\Delta(c/v)$] was 0.12 for 1 to 10 January and ~0.15 for all of January. These values of α and $\Delta(c/v)$ are in good agreement with previous measurements taken over similar paths.[7]

As we mentioned previously, all three submarines were located at a distance of approximately 5 Mm from WTF. The average daytime, sunrise and sunset transition periods (SRTP and SSTP), and nighttime field strengths measured on all three submarines were -150.1, -150.6, and -151.5 dBA/m, respectively. Based on the Connecticut measurements alone, the predicted field strengths at a distance of 5 Mm are -150.2, -150.7, and -151.2 dBA/m for daytime, transition period, and nighttime propagation, respectively, which shows excellent agreement with the measured field strengths.

The measured average difference in relative phase ($\Delta\phi$) between the nighttime and daytime periods during 1 to 10 January was 74 deg on submarine 1,

42 deg on submarine 2, and 50 deg on submarine 3. During 16 to 26 January, the average $\Delta\phi$ was 65 deg (see tables 1 and 2).

The average of these $\Delta\phi$'s is 58 deg, which, for a distance of 5 Mm, translates to a $\Delta(c/v)$ of 0.13. This value is also in excellent agreement with the $\Delta(c/v)$ value determined from the Connecticut measurements alone (table 3).

CONCLUSIONS

Adequate-quality ELF field-strength (both amplitude and relative phase) measurements were taken aboard three operational submarines during January 1977.

The effective-noise values measured on all three submarines was too high and exhibited little diurnal variation. It appears that the effective noise measured on all three submarines was contaminated by submarine-generated noise (external or internal to the submarine).

Field-strength measurements were also taken in Connecticut during January 1977. The average submarine measured field-strength and relative-phase values were in excellent agreement with the predicted values, which were based upon the Connecticut measurements alone.

Table 3. January 1977 Connecticut Field-Strength Averages

Date	Nighttime H_ϕ (dBA/m)	SRTP H_ϕ (dBA/m)	Daytime H_ϕ (dBA/m)	$\Delta\phi$ (Night-Day) (deg)
1/02/77	-146.5	-145.7	-145.1	12.9
1/03/77	-146.8	-146.1	-144.0	17.6
1/04/77	-145.0	-144.3	-142.8	17.9
1/05/77	-145.1	-145.5	-144.0	19.4
1/06/77	-146.9	-145.6	-144.2	23.3
1/07/77	-146.6	-145.9	-144.5	14.1
1/08/77	-146.6	-146.0	-144.9	14.5
1/09/77	-146.6	-146.1	-144.4	16.3
1/10/77	-146.5	-	-144.7	18.4
1/11/77	-145.9	-145.2	-144.1	11.0
1/12/77	-145.9	-145.3	-144.1	21.3
1/13/77	-146.2	-145.3	-144.1	20.9
1/14/77	-146.7	-145.4	-143.9	15.7
1/17/77	-	-	-144.2	-
1/18/77	-146.1	-144.9	-144.0	26.7
1/19/77	-147.4	-145.3	-143.6	22.5
1/20/77	-146.1	-145.3	-144.4	25.2
1/21/77	-146.2	-145.2	-144.3	24.0
1/22/77	-147.1	-145.6	-144.6	27.5
1/23/77	-146.6	-145.9	-144.5	17.3
1/24/77	-146.8	-145.7	-143.9	20.8
1/25/77	-146.3	-145.5	-144.6	25.5
1/26/77	-146.5	-145.4	-144.2	22.4
1/27/77	-146.0	-145.6	-145.0	32.0
1/28/77	-146.9	-145.7	-144.6	30.4
1/29/77*	-147.4	-145.1	-144.9	26.3
1/30/77*	-147.2	-144.1	-144.0	23.4
1/31/77*	-146.9	-146.0	-144.4	22.2
January Average	-146.3	-145.4	-144.2	21.0

$*\psi'$ = 200 deg.

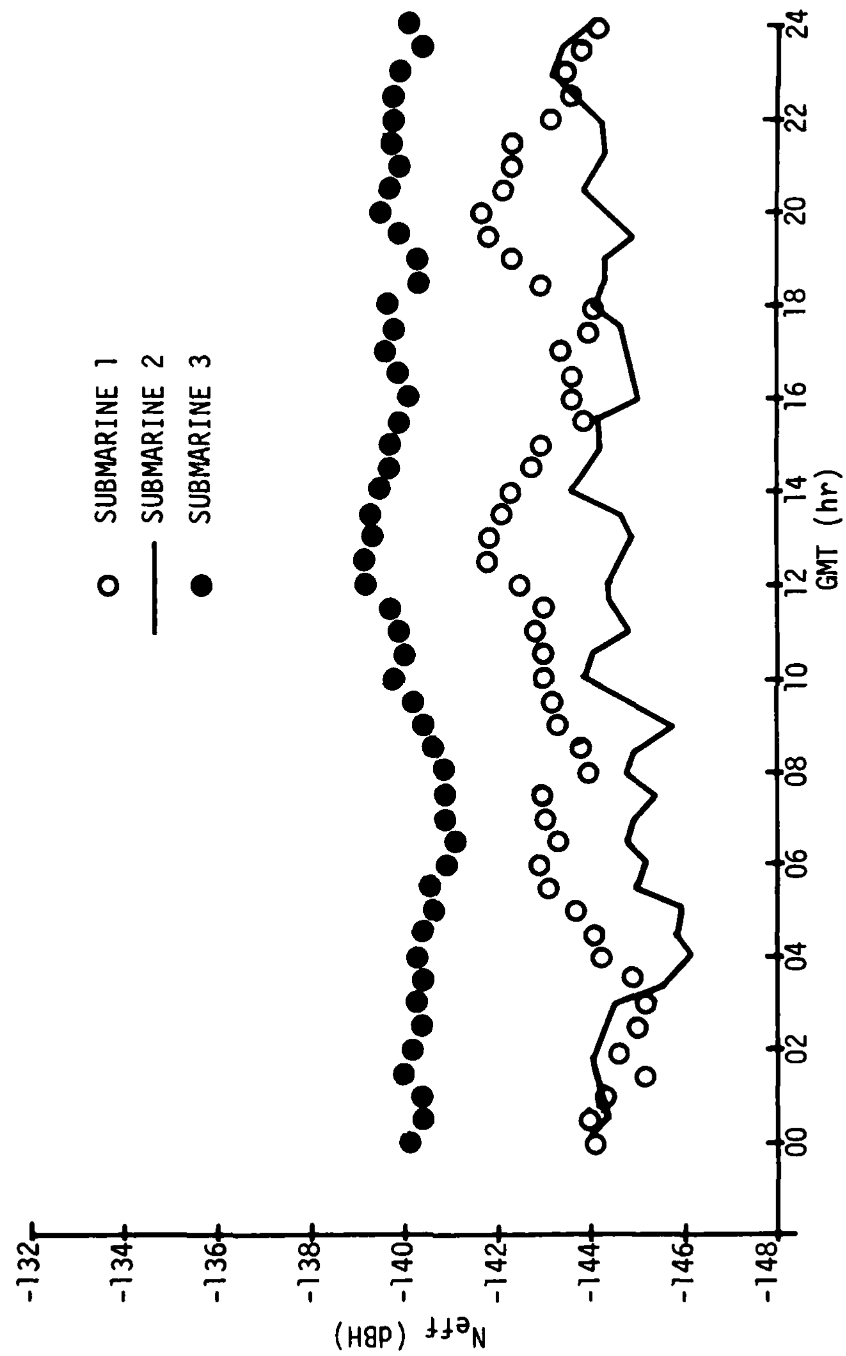

Figure 1. Submarine Average Effective-Noise Data Versus GMT

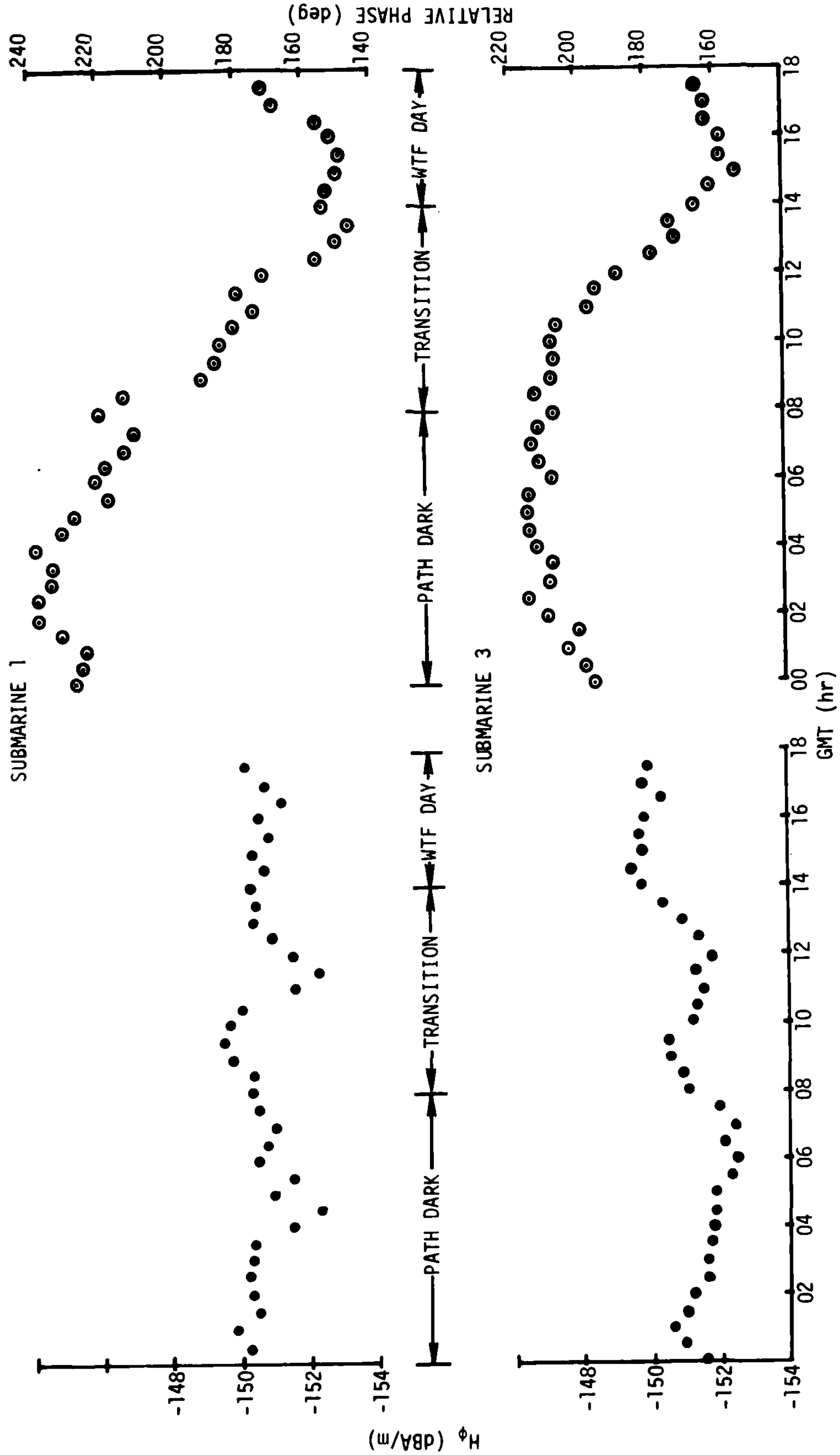

Figure 2. Submarines 1 and 3 Average Field Strengths Versus GMT, 1 to 10 January 1977

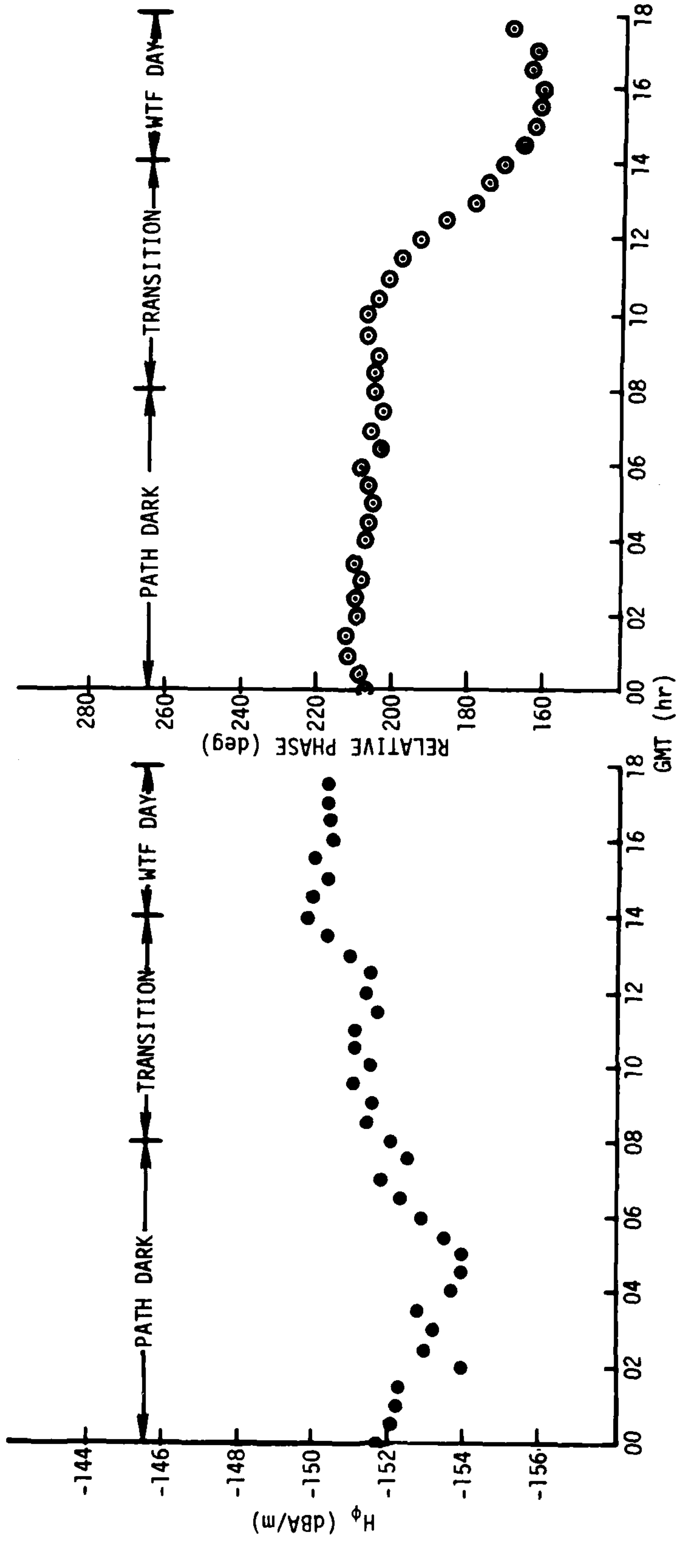

Figure 3. Submarine 2 Average Field Strength Versus GMT, 31 December to 5 January 1977

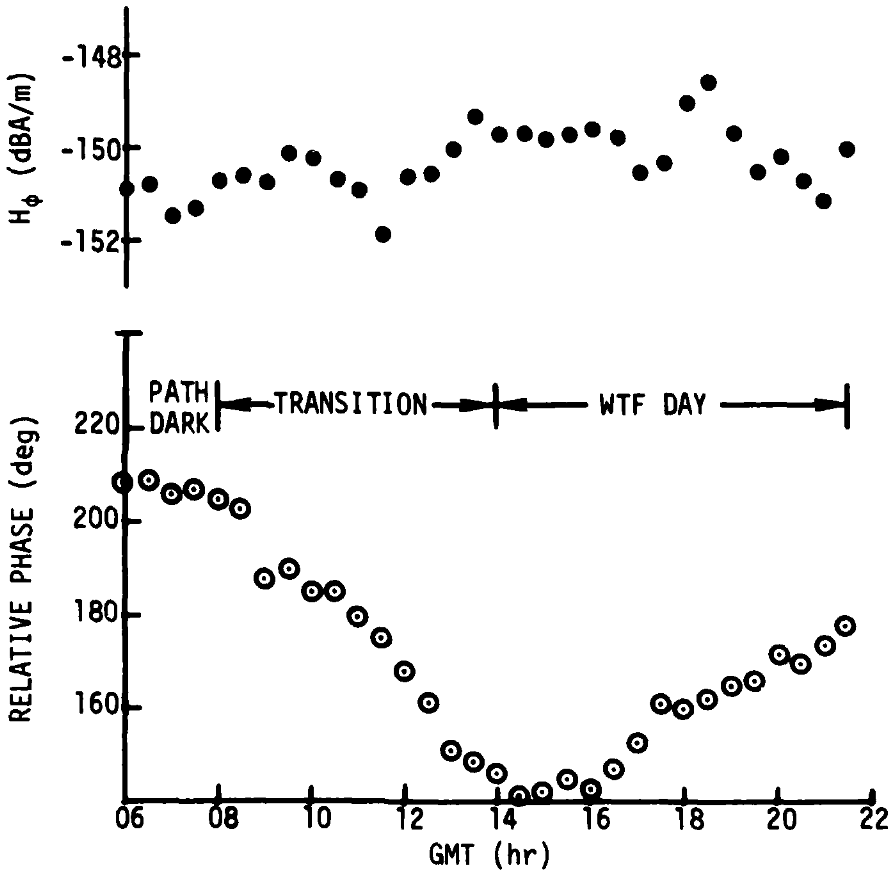

Figure 4. Submarine 3 Average Field Strength Versus GMT, 16 to 26 January 1977

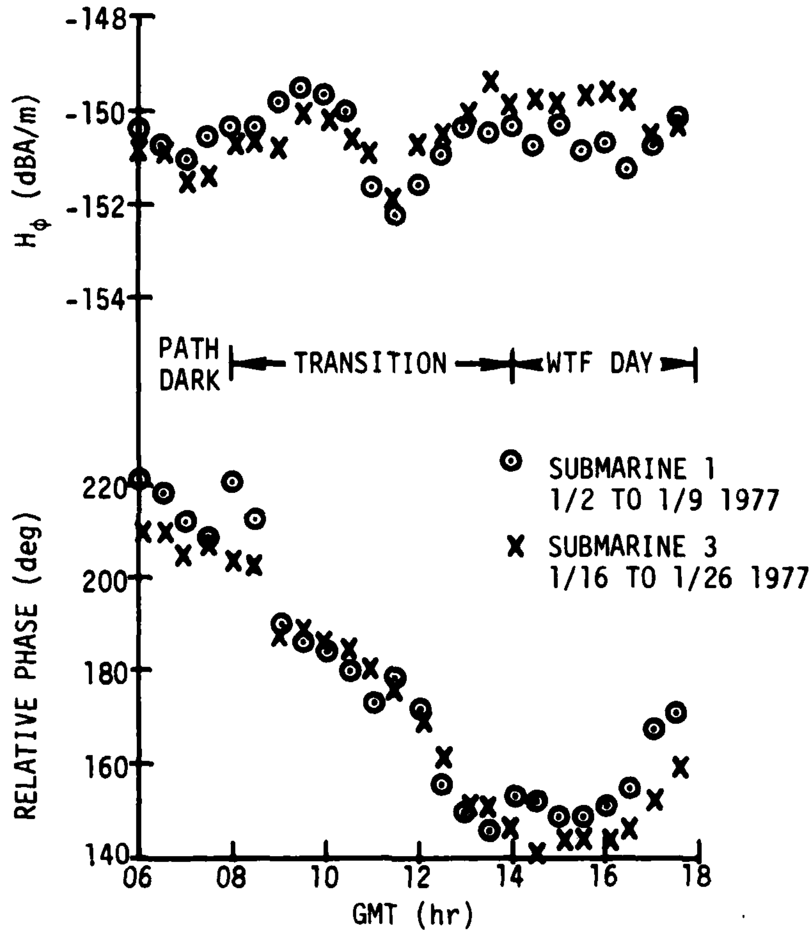

Figure 5. Comparison of Submarines 1 and 3 Field Strengths for Different Time Periods in January 1977

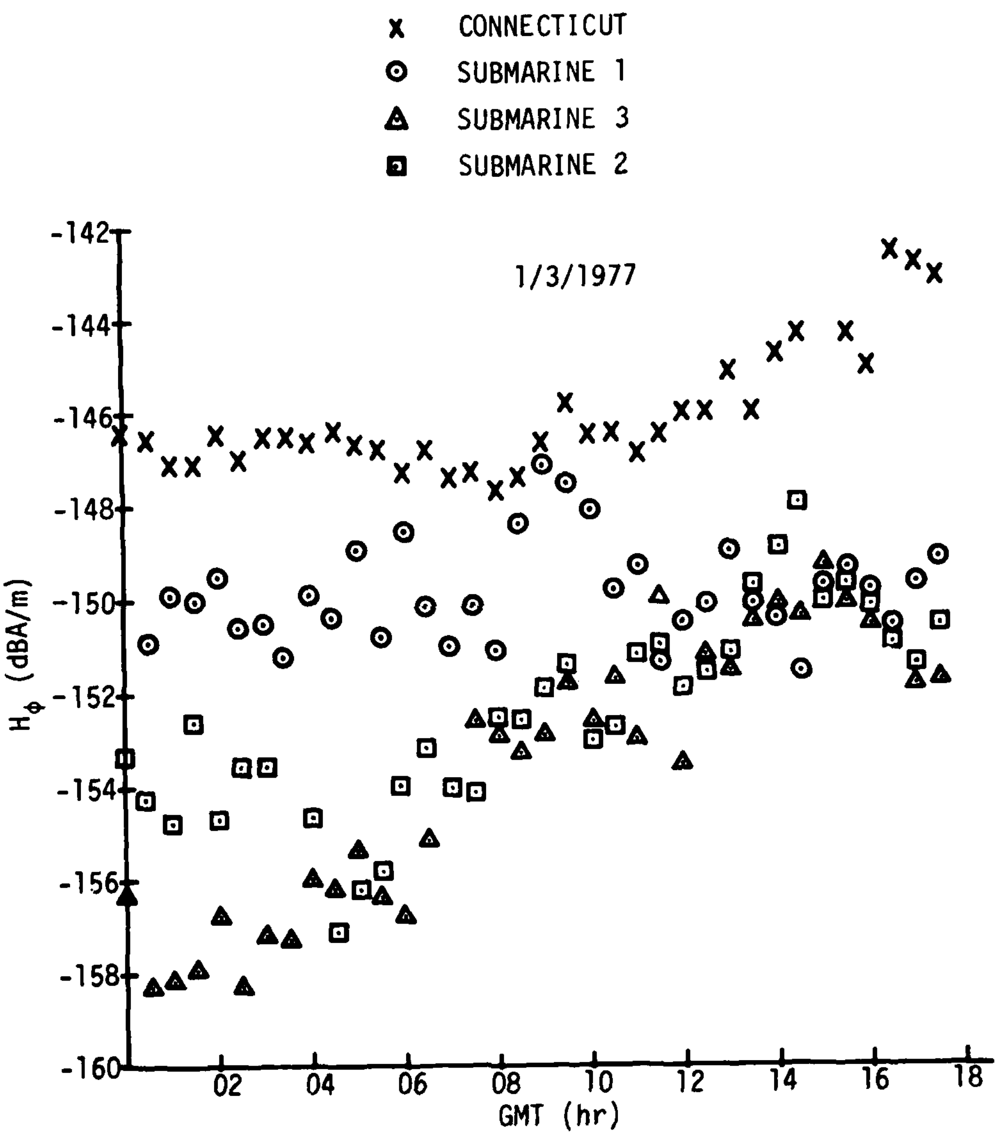

Figure 6. Comparison of Connecticut and Submarine Data, 3 January 1977

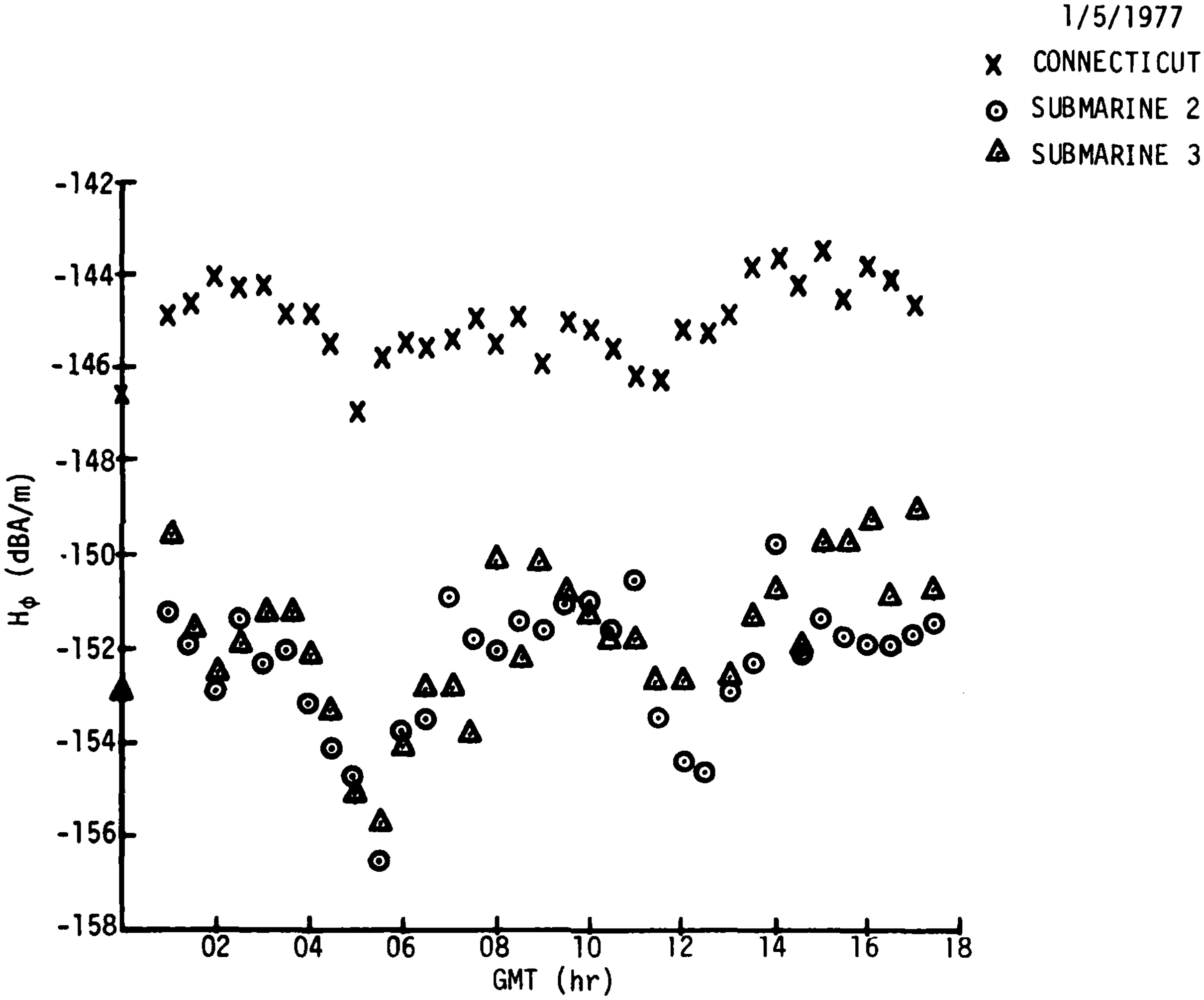

Figure 7. Comparison of Connecticut and Submarines 2 and 3 Data, 5 January 1977

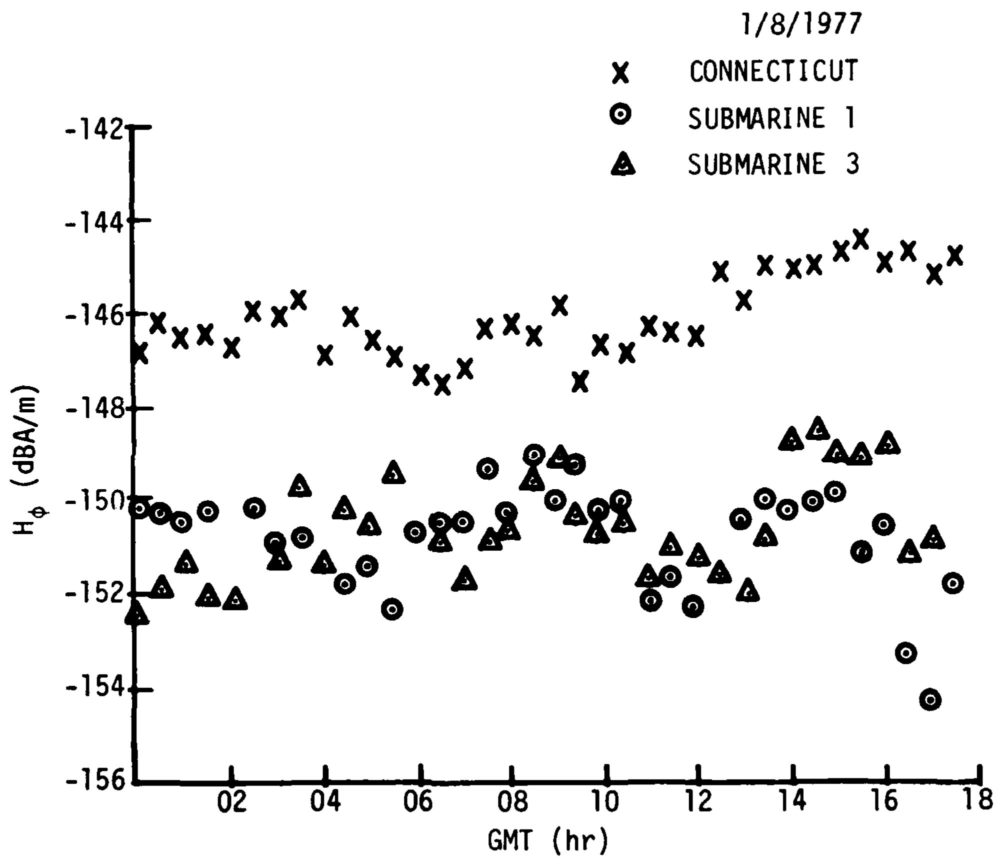

Figure 8. Comparison of Connecticut and Submarines 1 and 3 Data, 8 January 1977

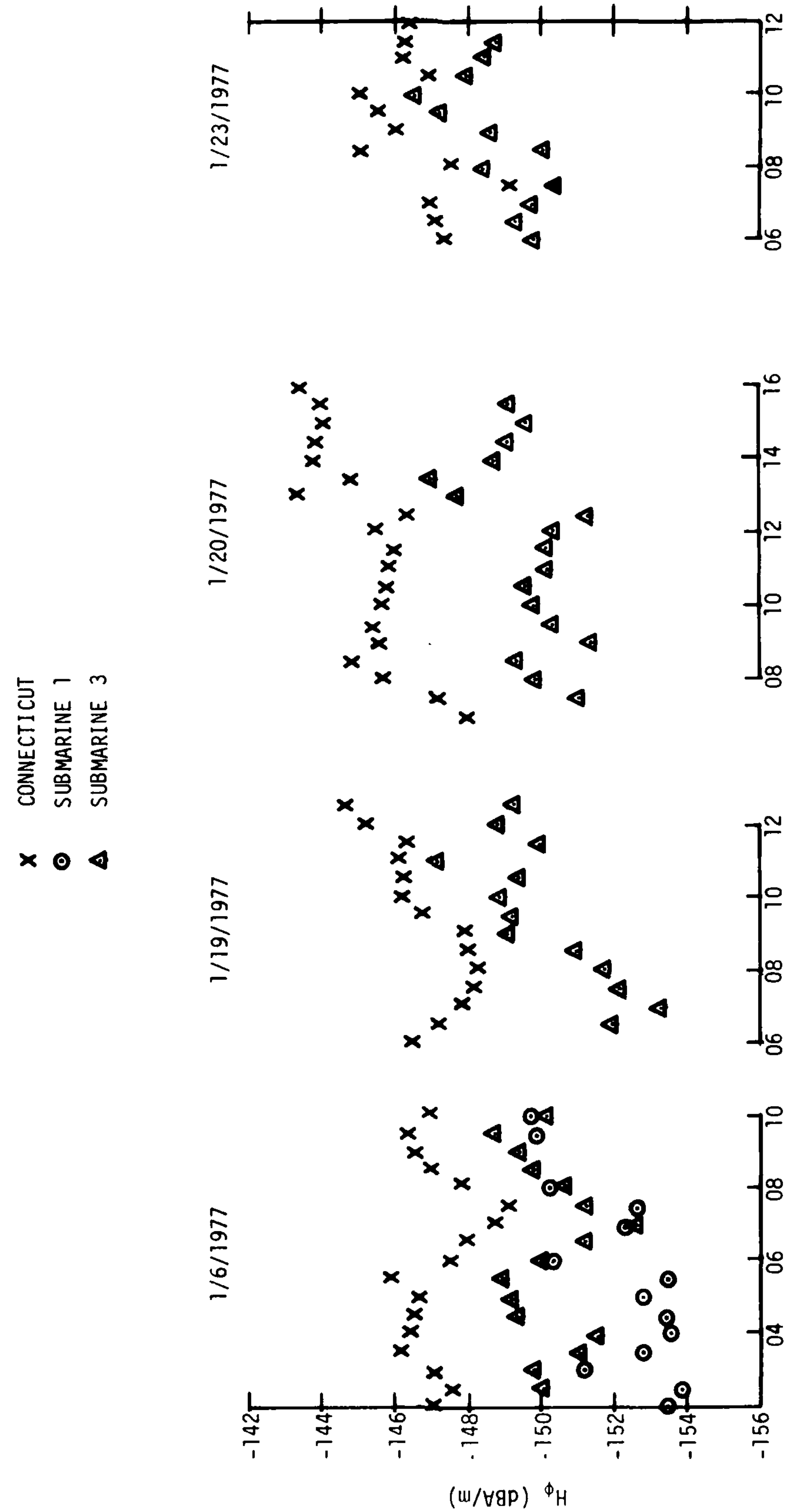

Figure 9. Further Comparisons of Connecticut and Submarine Data (6, 19, 20, and 23 January 1977)

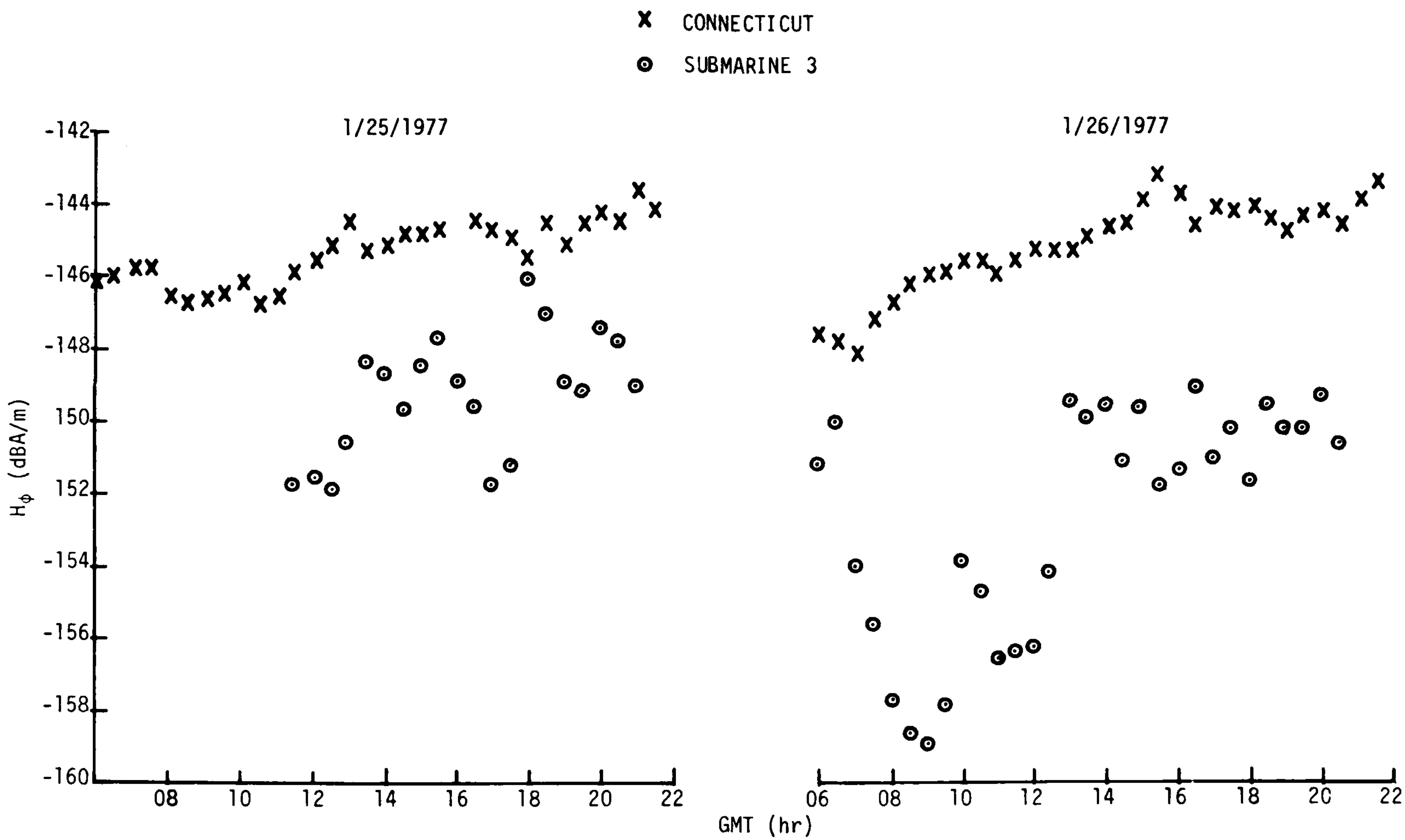

Figure 10. Comparison of Connecticut and Submarine Data, 25 and 26 January 1977

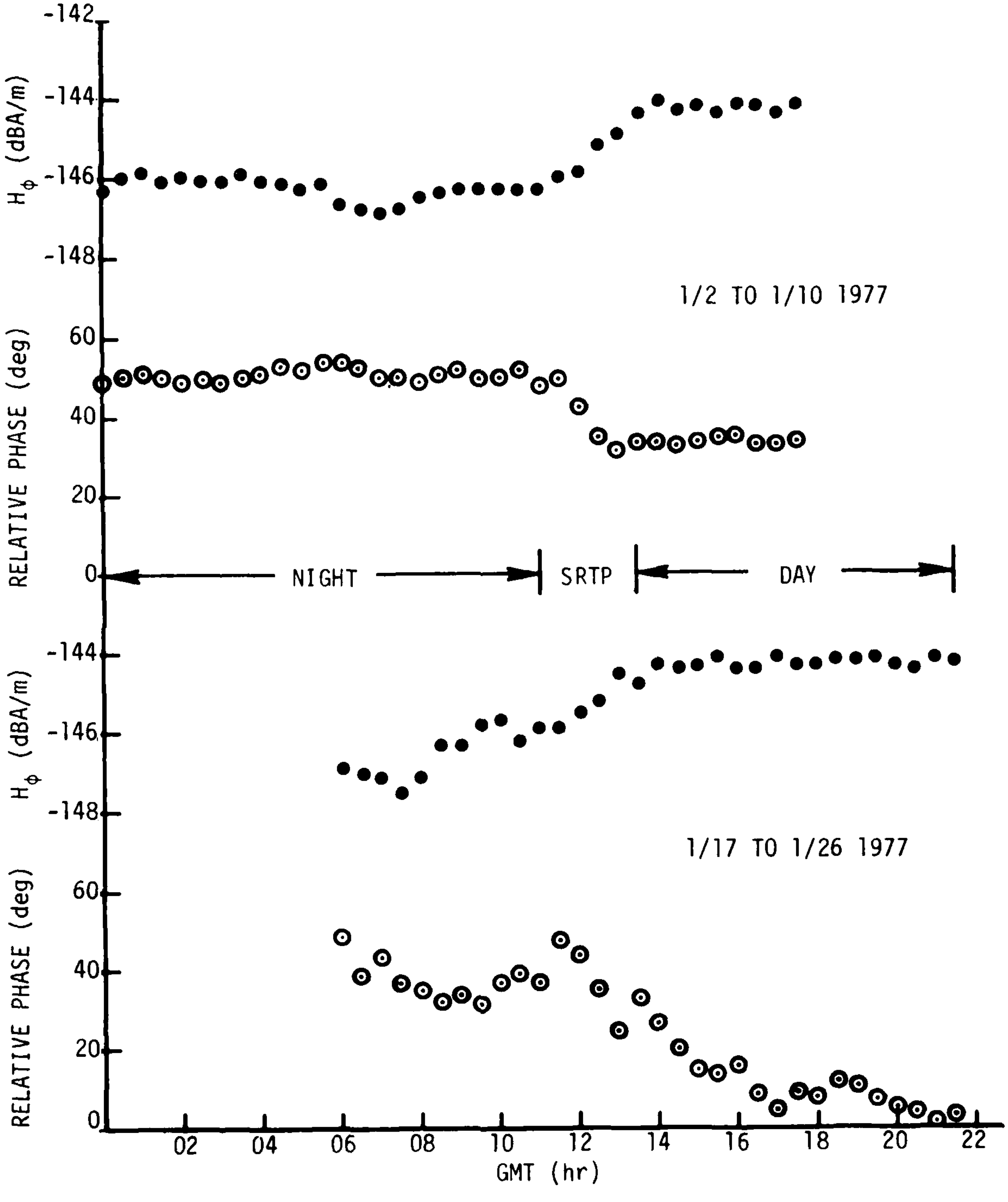

Figure 11. Connecticut Field-Strength Averages Versus GMT, 2 to 10 and 17 to 26 January 1977

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Appendix A

SUBMARINE DAILY DATA

The daily field-strength values (both amplitude and relative phase) taken aboard three submarines are plotted versus GMT in this appendix. Submarine 2 data are plotted in figures A-1 to A-3, submarine 1 data in figures A-4 to A-6, and submarine 3 data in figures A-7 to A-15.

Referring to the submarine 2 data (figures A-1 to A-3), we see that amplitude peak-to-trough variations of 6 to 9 dB occurred during 1, 2, 3, and 5 January, while the largest daily field-strength difference (9.2 dB) was measured on 3 January (-157.2 dBA/m at 0430 to -148.0 dBA/m at 1430). On 2, 3, and 5 January, the minimum nighttime field strengths occurred from 0400 to 0600 GMT. The night-to-day relative-phase variation was 49 ±2 deg on 31 December and 2, 4, and 5 January. However, during 1 and 3 January, the $\Delta\phi$ variation was only 23 to 32 deg (i.e., 17 to 26 deg less).

From the submarine 1 data (figures A-4 to A-6), we see that amplitude peak-to-trough variations of 4 to 6 dB occurred during each day. The relative-phase data exhibited much more variation than did the submarine 2 data. The night-to-day relative-phase variation was 74 ±8 deg from 4 through 8 January. However, during 3 January, the $\Delta\phi$ variation was only 55 deg (19 deg less), while on 9 January, the $\Delta\phi$ variation was 93 deg (19 deg more).

Referring to the 1 to 10 January submarine 3 data (figures A-7 through A-11), we see that amplitude peak-to-trough variations of 5 to 9 dB occurred during 1, 2, 3, 5, and 6 January. The largest daily field-strength difference (9 dB) was also measured on 3 January (-158.3 dBA/m at 0230 to -149.3 dBA/m at 1500). The night-to-day relative-phase variation was 56 ±12 deg for 7 out of 9 nights. However, during 3 and 8 January, the $\Delta\phi$ variation was only 23 to 35 deg (21 to 33 deg less).

From the 16 to 26 January submarine 3 data (figures A-7 through A-15), we see that the night-to-day relative-phase plots were essentially trapezoidal with little variation (i.e., $\Delta\phi$ = 65 ±10 deg). However, the amplitude data exhibited substantial variations. Amplitude peak-to-trough variations of 5 to 10 dB occurred during 7 of the 8 days measured, while the largest daily field-strength difference (9.9 dB) was measured on 26 January (-158.9 dBA/m at 0900 to -149.0 dBA/m at 1630).

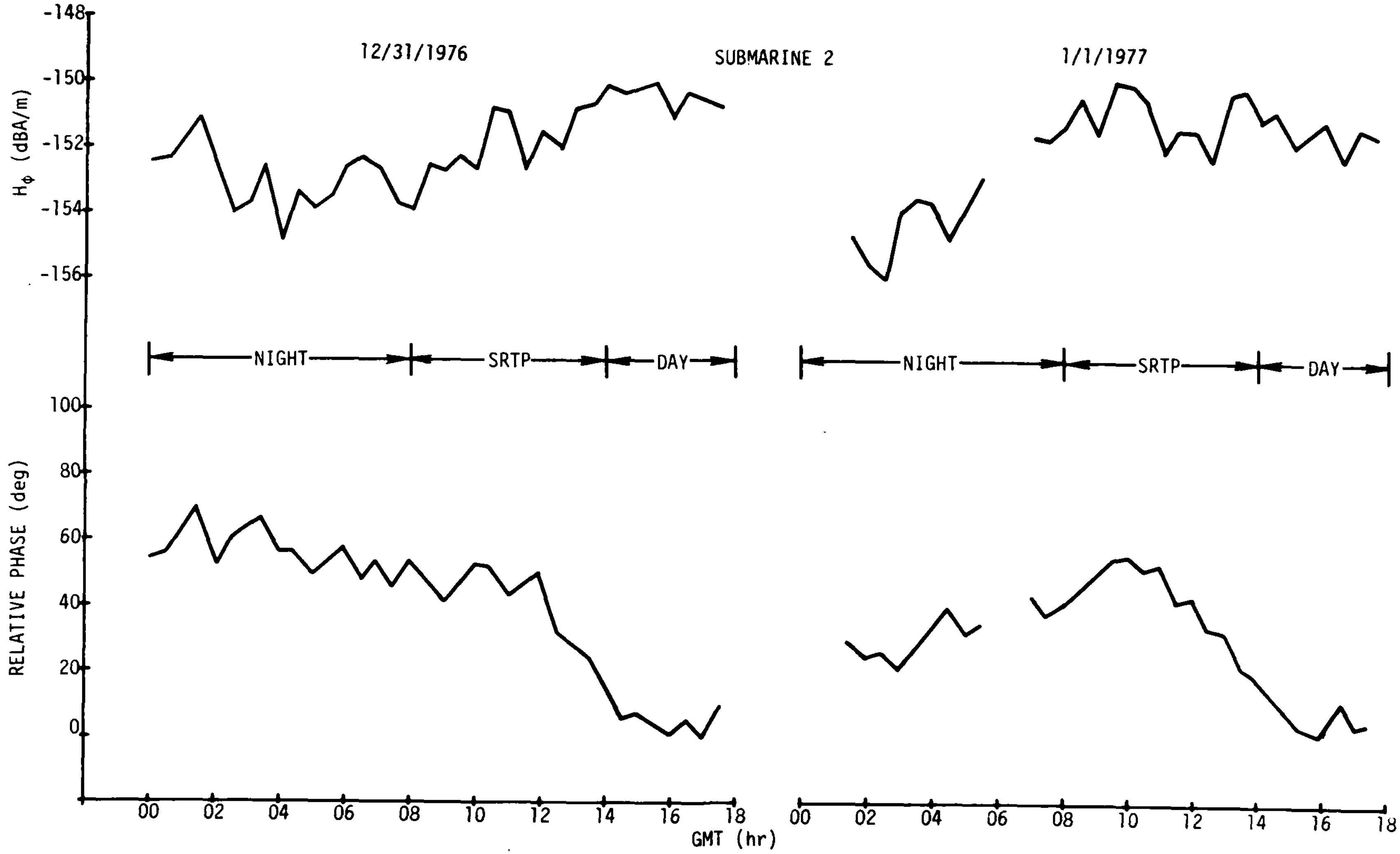

Figure A-1. Submarine 2 Field Strength Versus GMT, 31 December and 1 January 1977

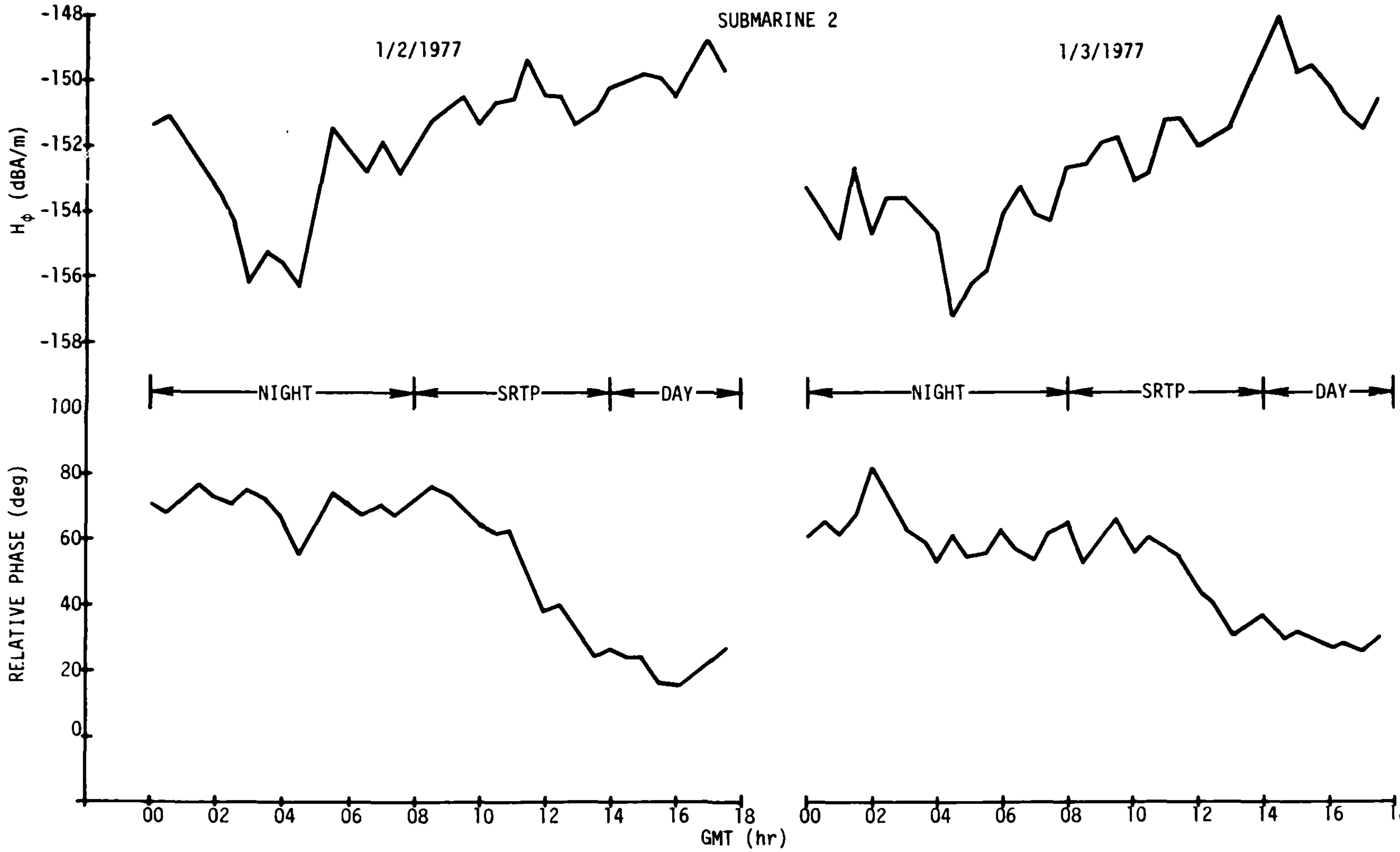

Figure A-2. Submarine 2 Field Strength Versus GMT, 2 and 3 January 1977

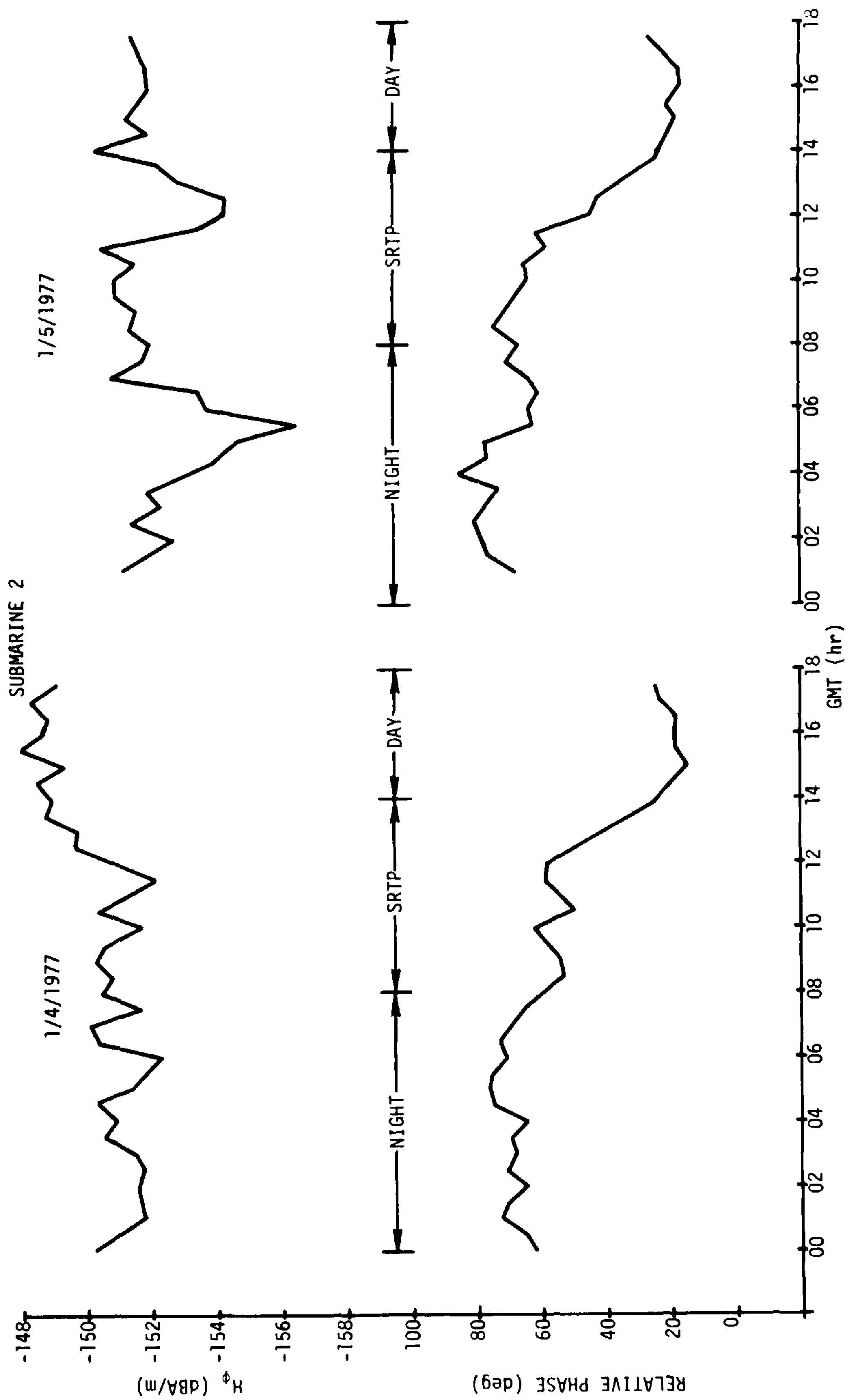

Figure A-3. Submarine 2 Field Strength Versus GMT, 4 and 5 January 1977

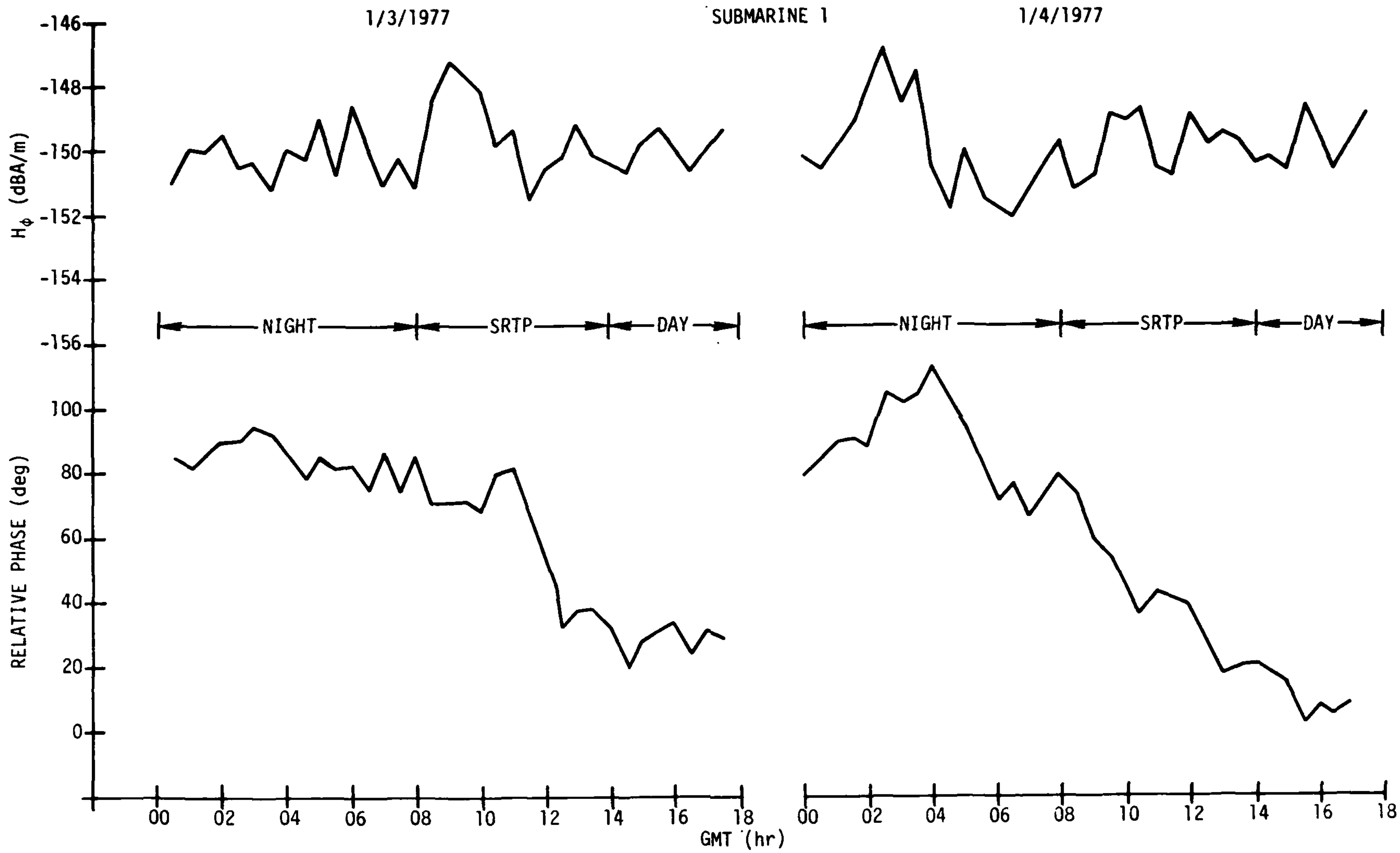

Figure A-4. Submarine 1 Field Strength Versus GMT, 3 and 4 January 1977

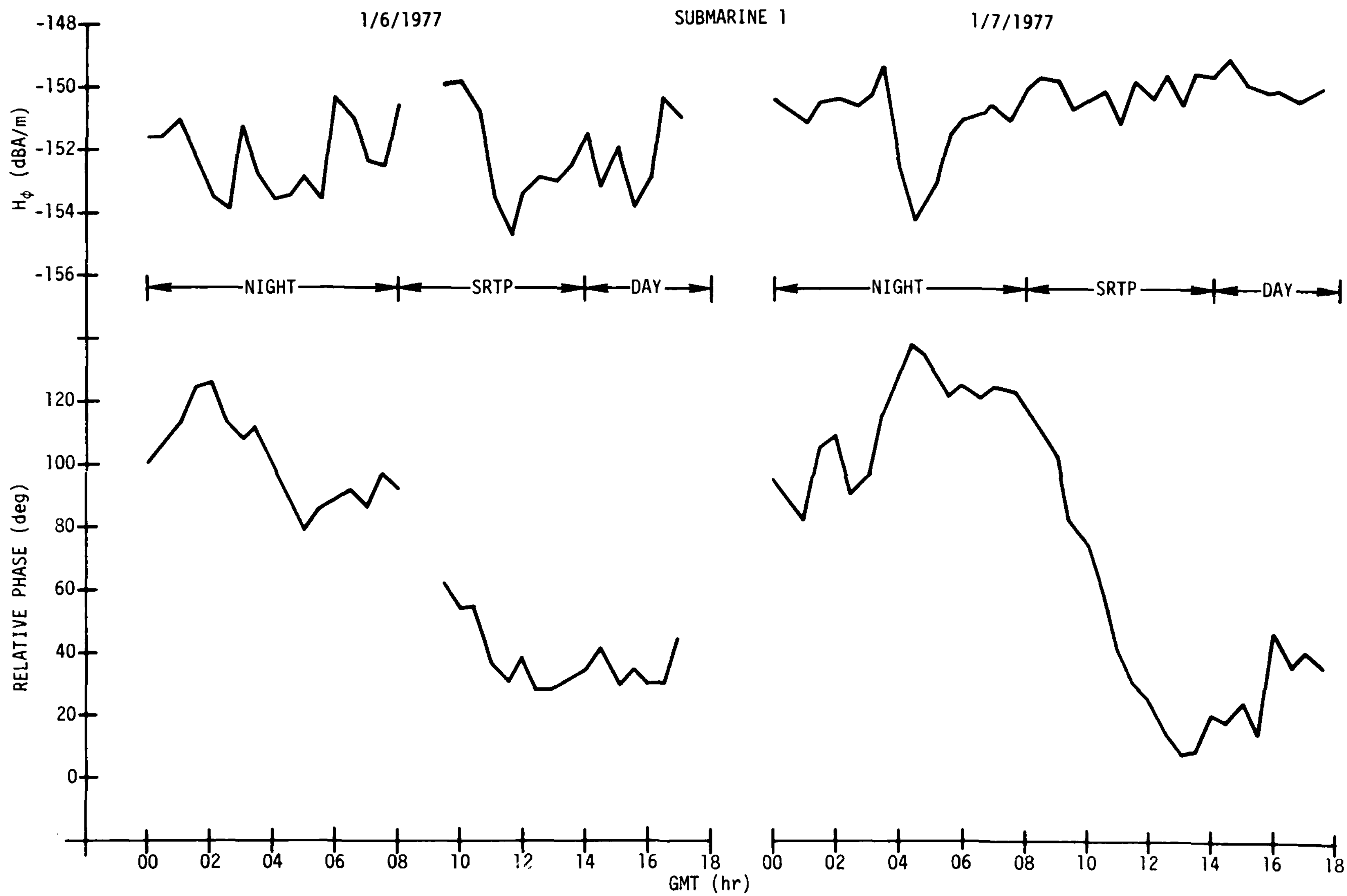

Figure A-5. Submarine 1 Field Strength Versus GMT, 6 and 7 January 1977

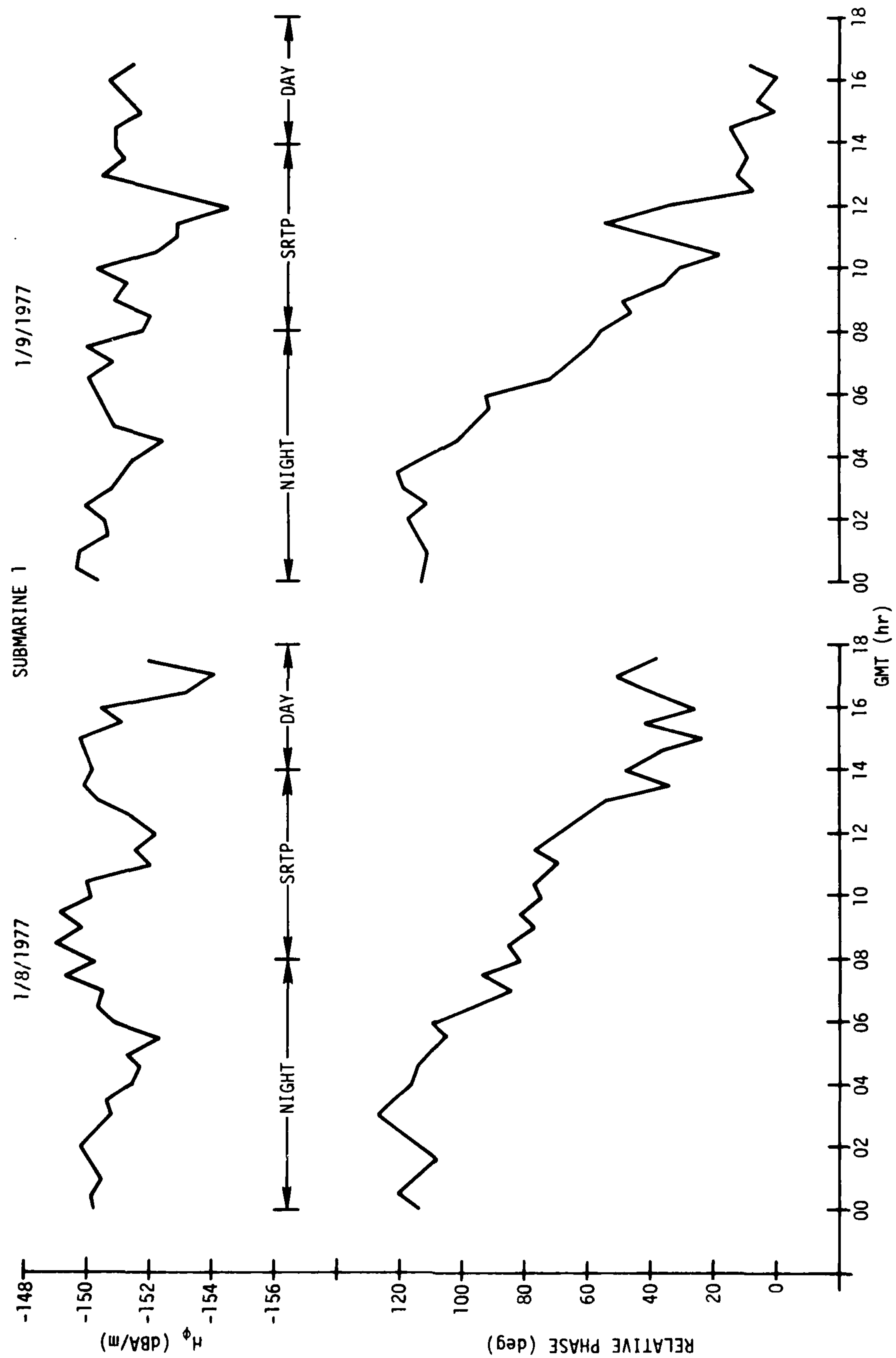

Figure A-6. Submarine 1 Field Strength Versus GMT, 8 and 9 January 1977

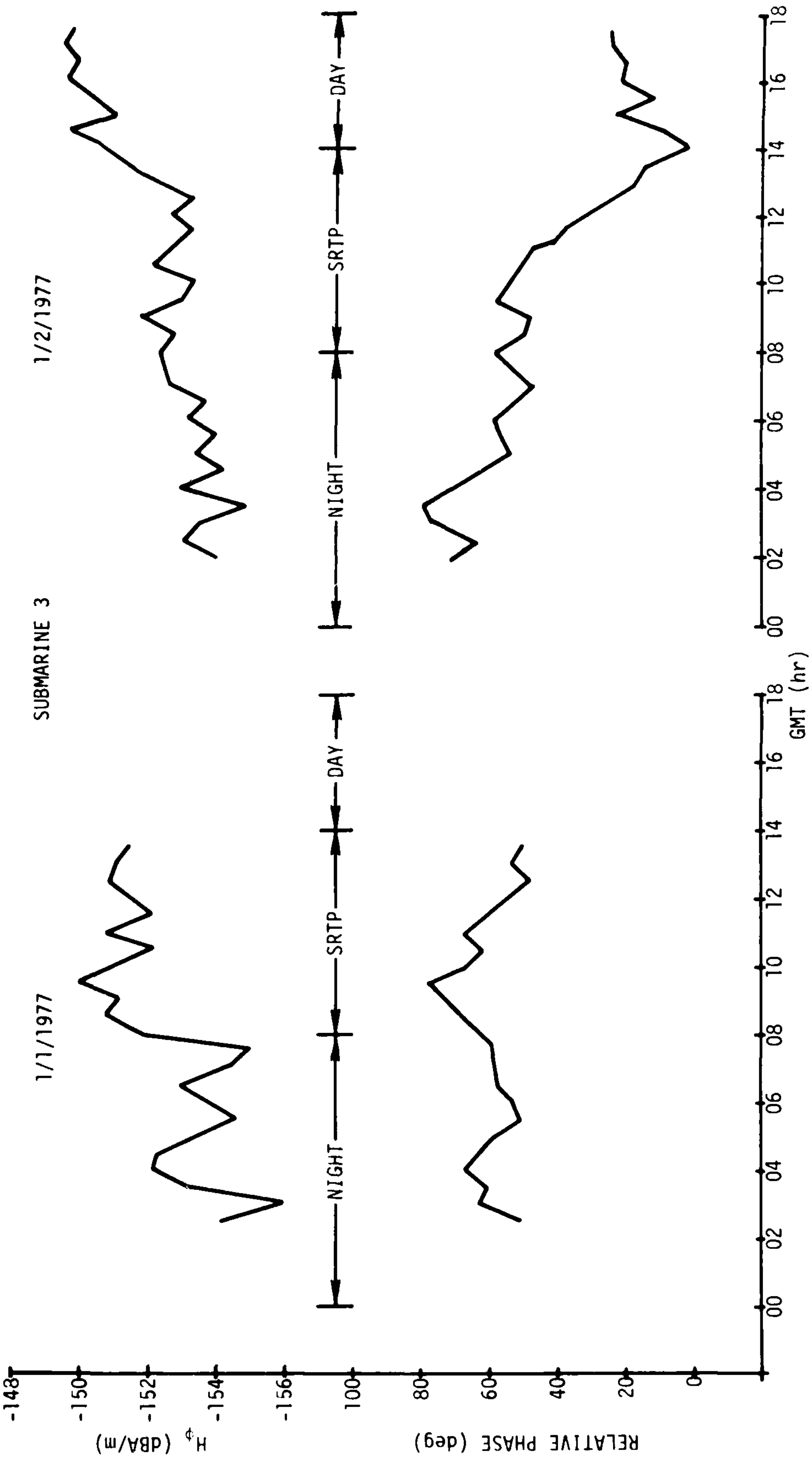

Figure A-7. Submarine 3 Field Strength Versus GMT, 1 and 2 January 1977

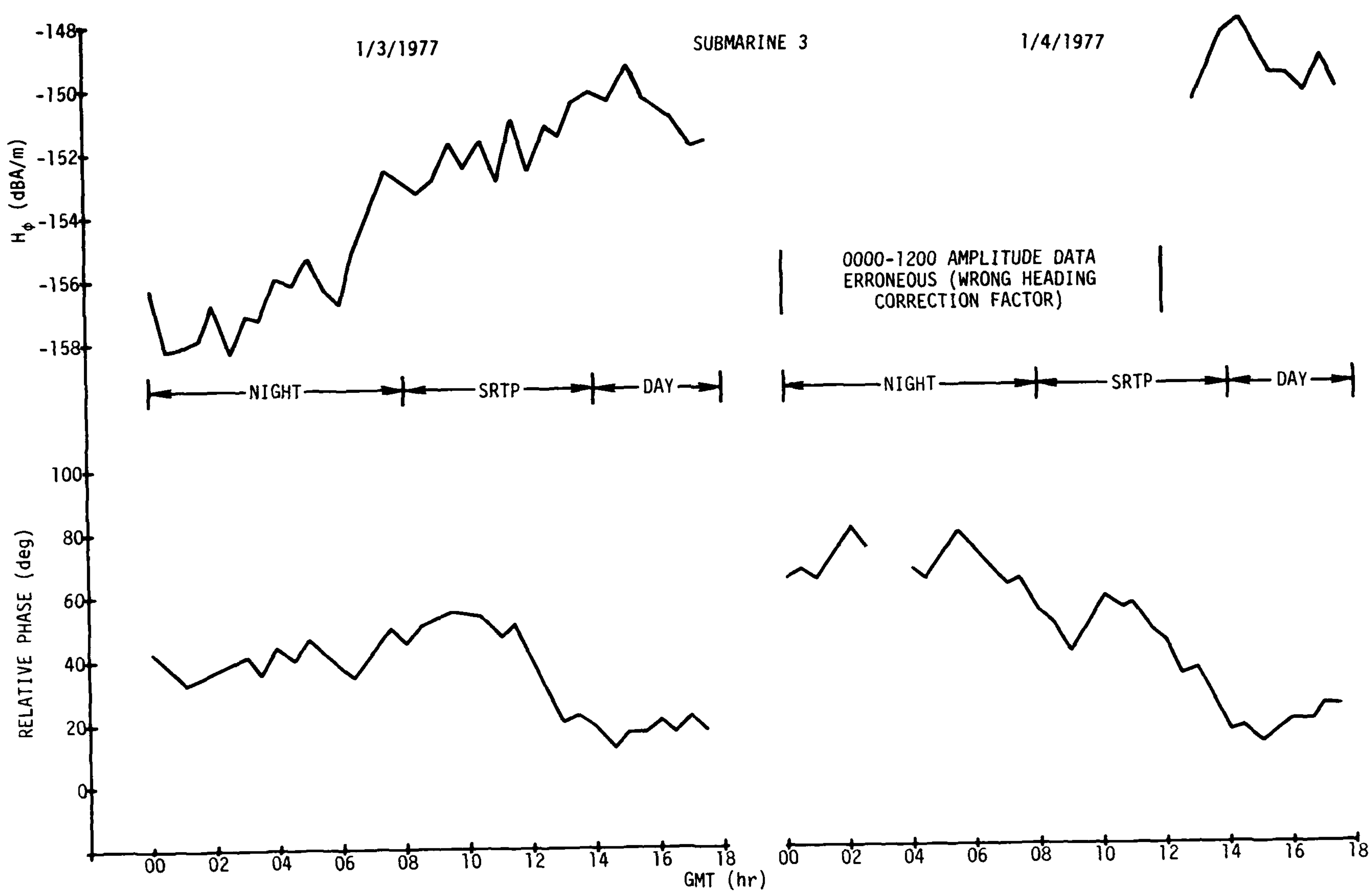

Figure A-8. Submarine 3 Field Strength Versus GMT, 3 and 4 January 1977

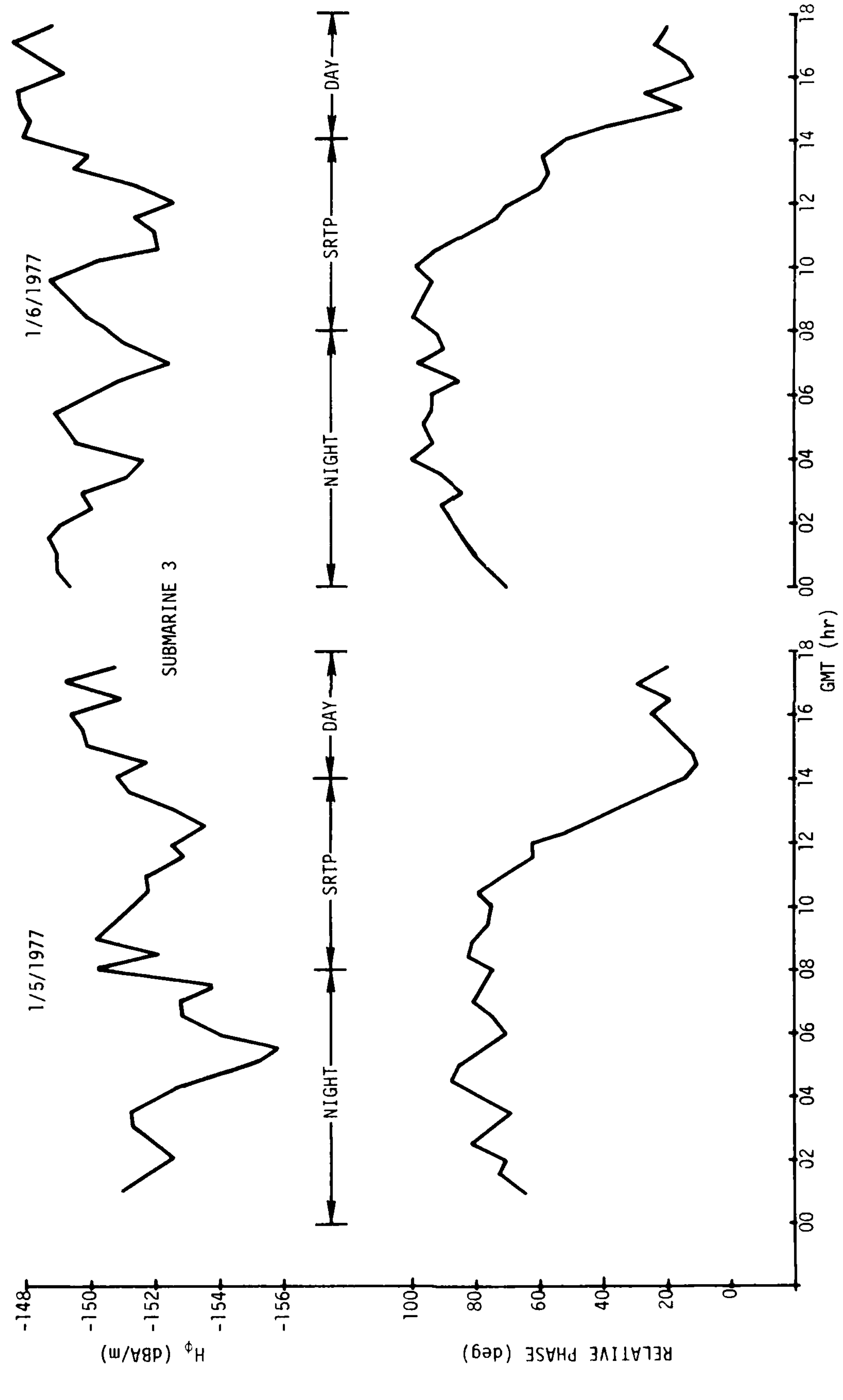

Figure A-9. Submarine 3 Field Strength Versus GMT, 5 and 6 January 1977

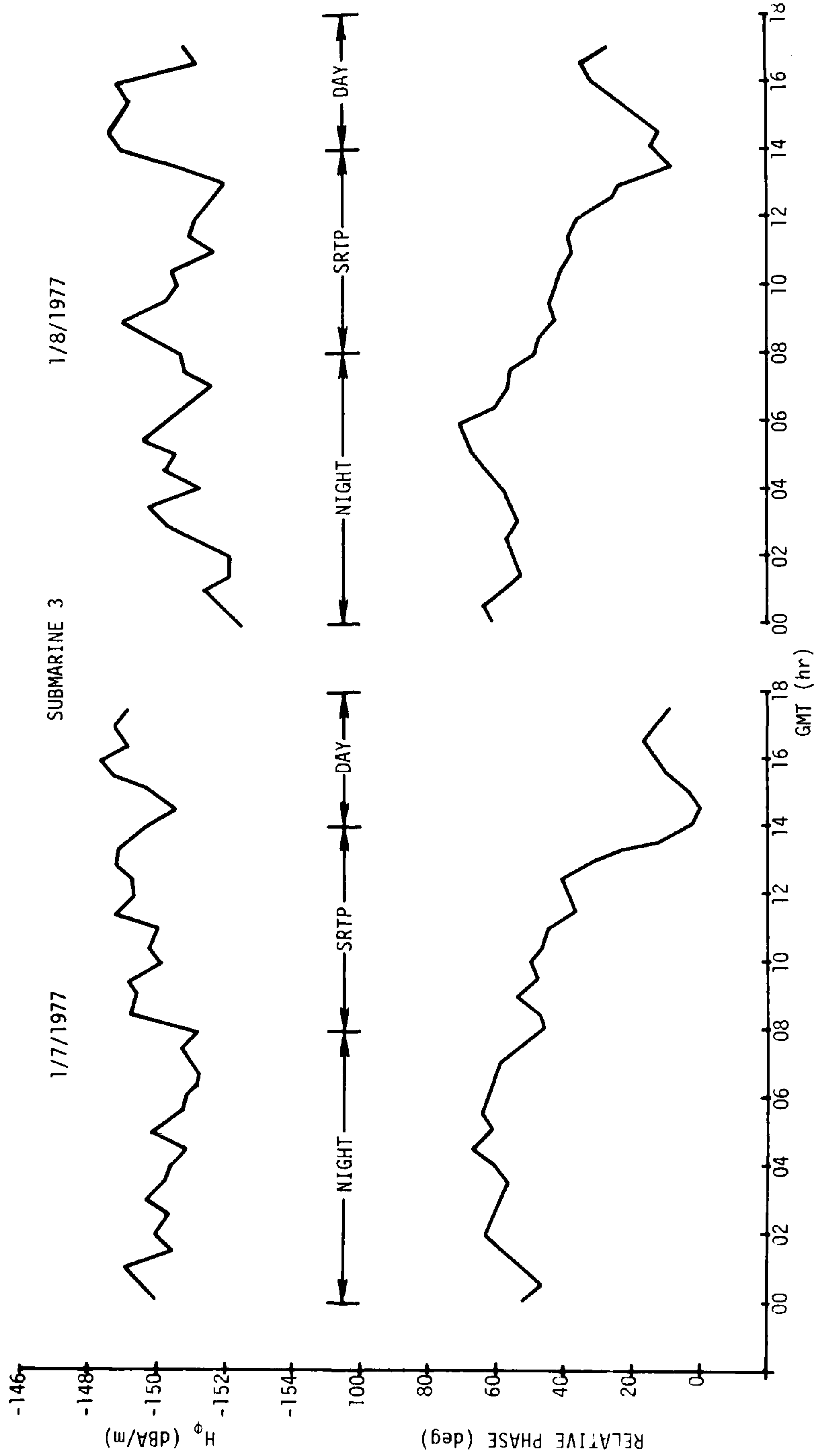

Figure A-10. Submarine 3 Field Strength Versus GMT, 7 and 8 January 1977

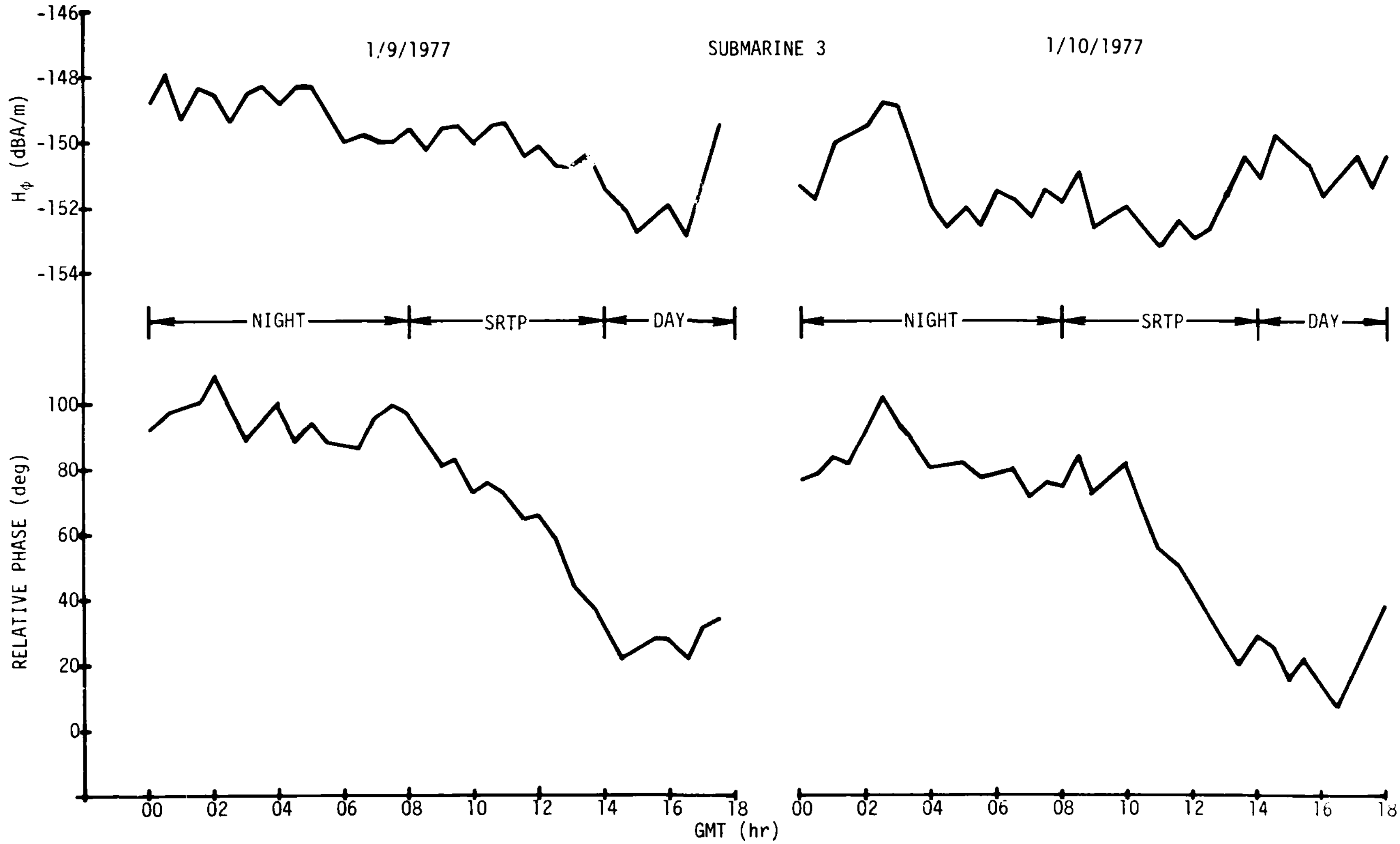

Figure A-11. Submarine 3 Field Strength Versus GMT, 9 and 10 January 1977

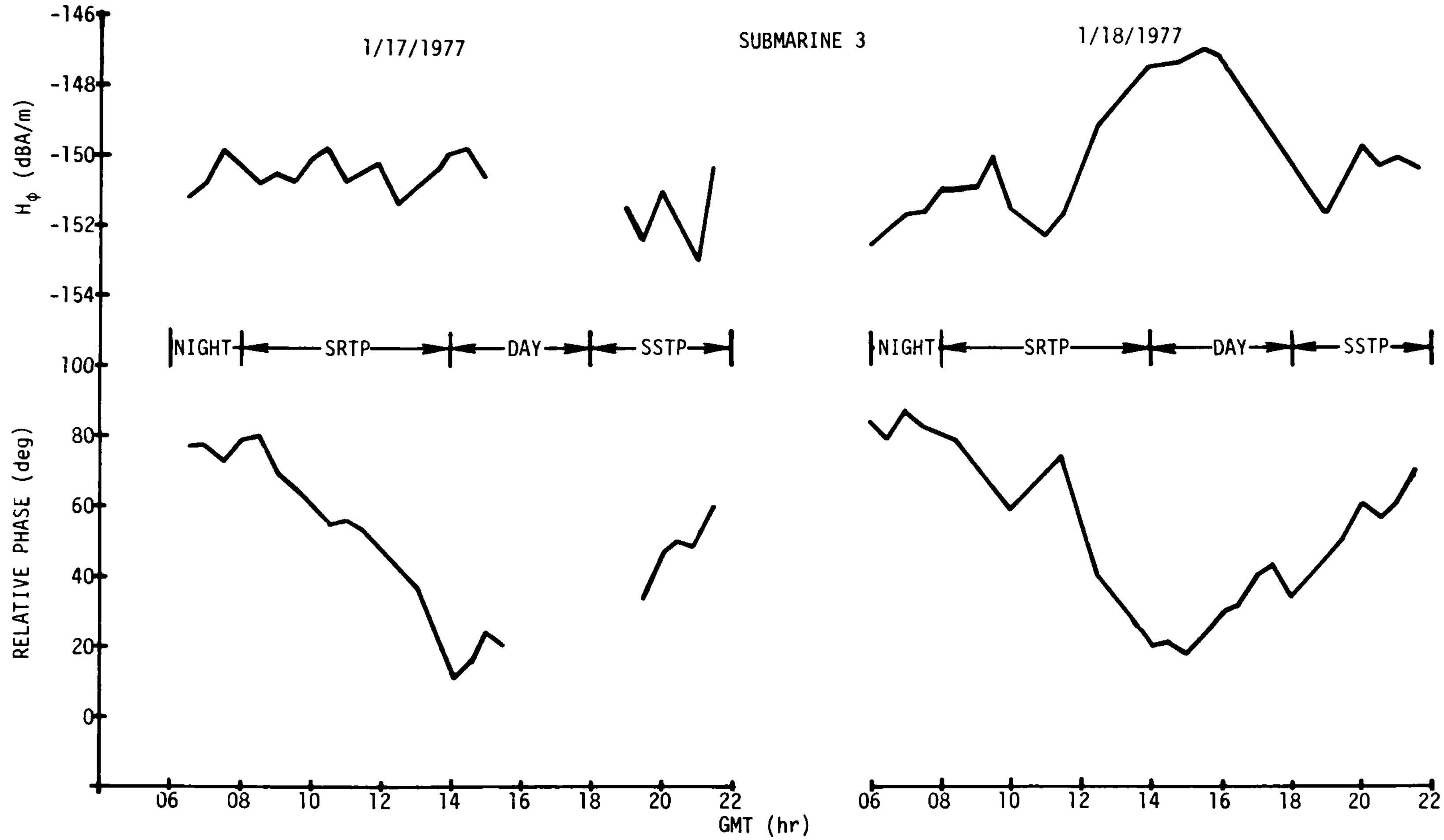

Figure A-12. Submarine 3 Field Strength Versus GMT, 16, 17, and 18 January 1977

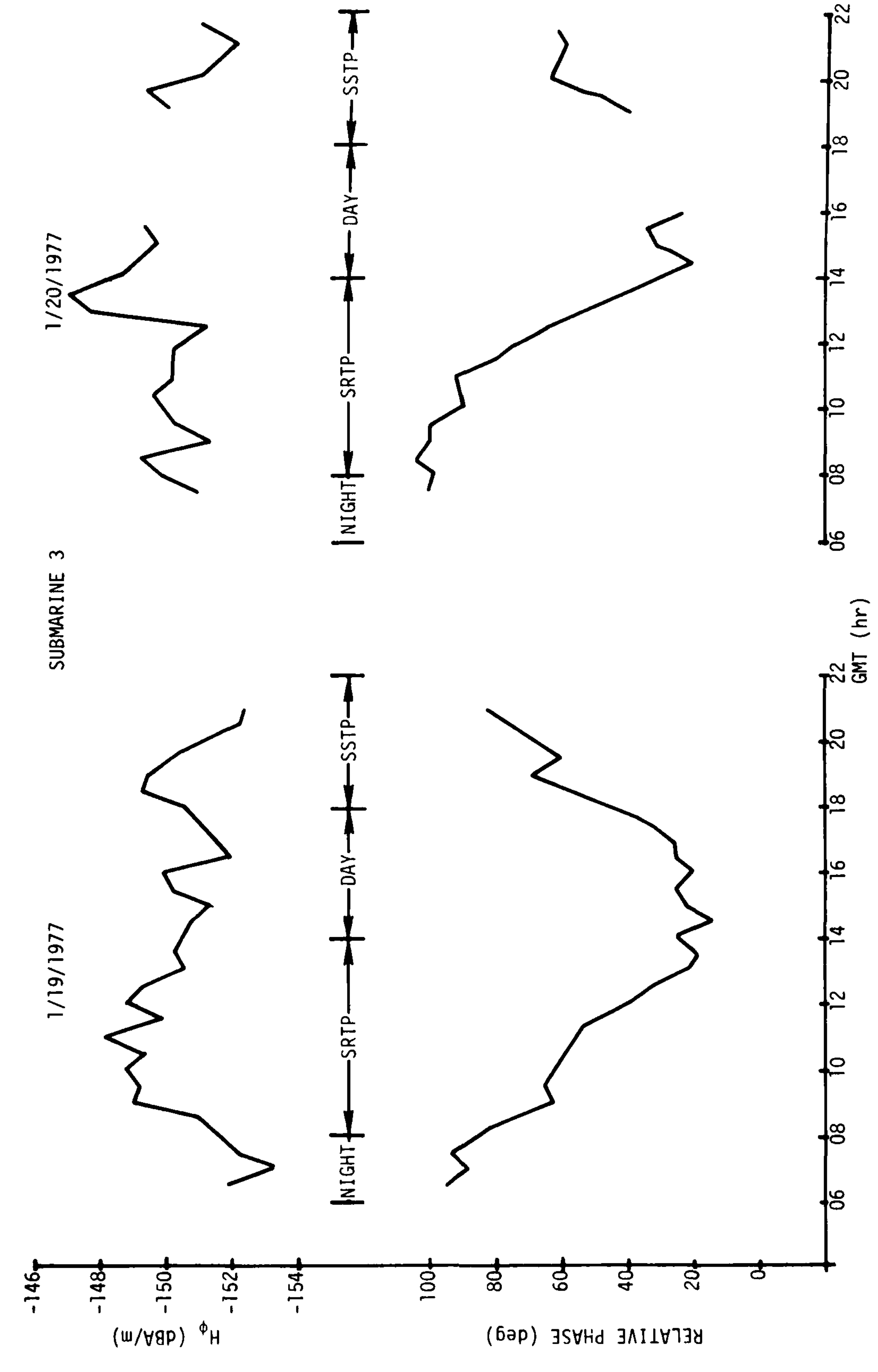

Figure A-13. Submarine 3 Field Strength Versus GMT, 19 and 20 January 1977

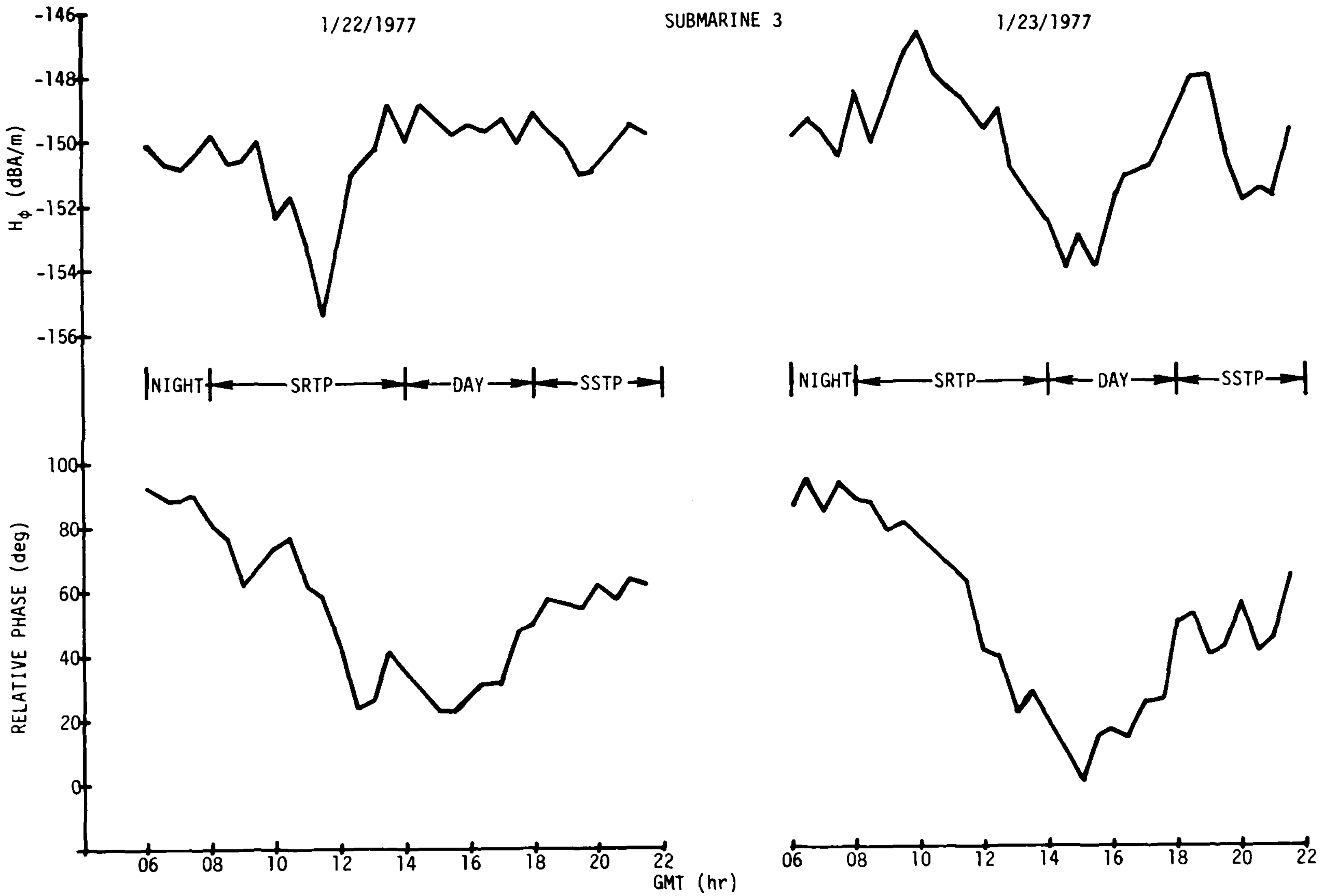

Figure A-14. Submarine 3 Field Strength Versus GMT, 22 and 23 January 1977

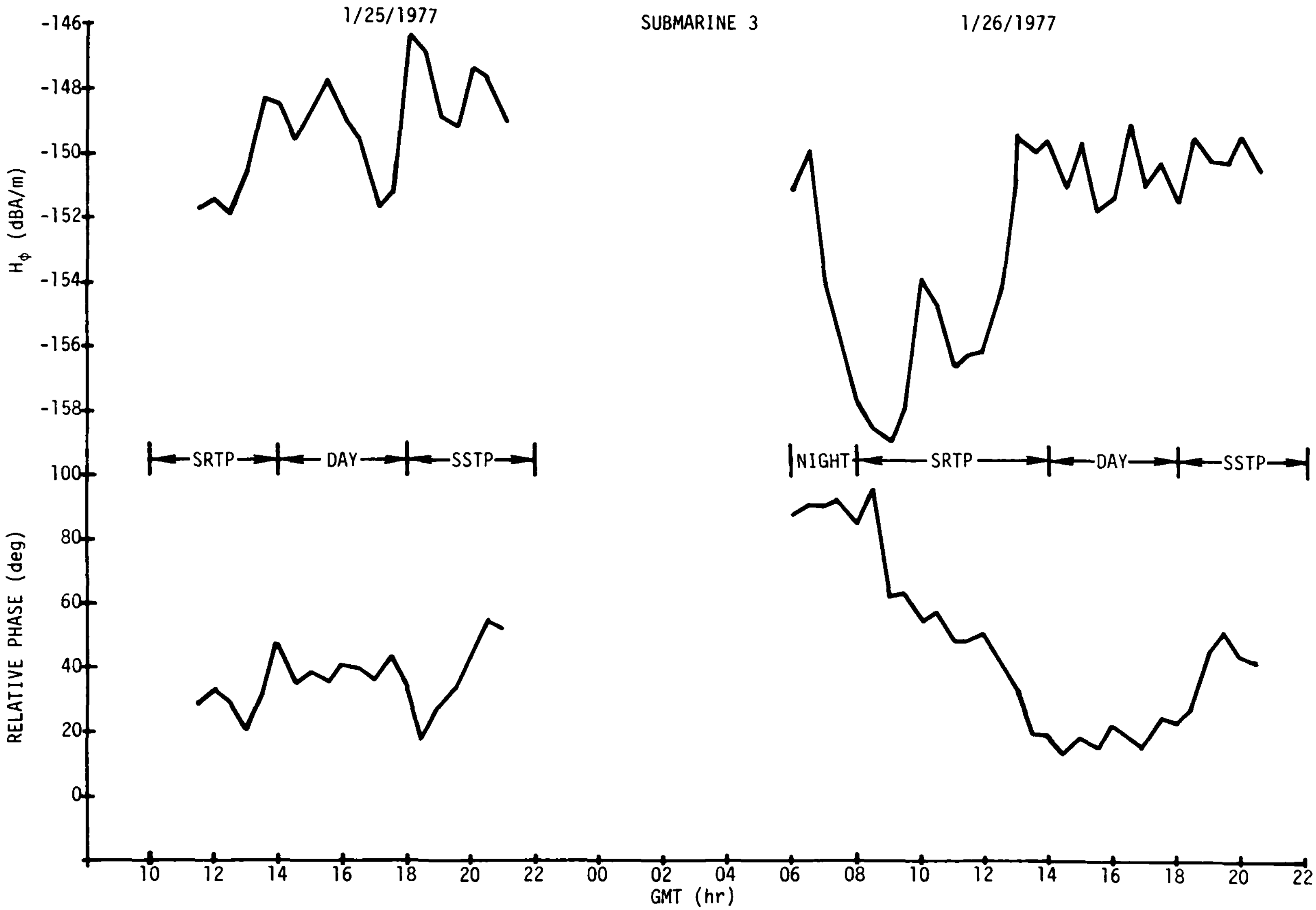

Figure A-15. Submarine 3 Field Strength Versus GMT, 25 and 26 January 1977

Appendix B

CONNECTICUT DAILY DATA

For the Connecticut measurements, the AN/BSR-1 receiver is located in Room 3111 of Building 80 at the Naval Underwater Systems Center (NUSC), New London, CT. The loop receiving antenna is located at Fishers Island, NY (about 10 km from New London). The receiver and receiving antenna are connected by means of a microwave link from Fishers Island to NUSC. The receiving antenna is located approximately 50 m from an NUSC building at Fishers Island which houses the ELF preamplifier and associated circuitry.

From late November 1976 to mid-January 1977, a faulty heater motor bearing (located in the NUSC building at Fishers Island) was a strong source of 49- and 71-Hz interference (i.e., 60 ±11 Hz). Thus, during that period, the Connecticut effective-noise measurements were contaminated by industrial noise. The measured (contaminated) effective noise from late November to mid-January was -138 to -140 dBH, with little or no diurnal variation.

However, from 17 to 27 January, the 49- and 71-Hz interference levels decreased considerably. The effective-noise values measured during this period (which may still be somewhat contaminated by industrial noise) are plotted versus GMT in figure B-1. As expected, the minimum values occur around local sunrise and the maximum around local sunset. However, the average diurnal variation is only 2 dB, as compared to 5 dB measured during the fall of 1976. The Connecticut effective-noise values are approximately equal to the lowest values measured aboard any of the three submarines during January 1977 (see figure 1 in main text).

The daily field-strength (both amplitude and relative phase) values measured during January 1977 are presented in figures B-2 through B-23.

During the first half of January (figures B-2 through B-8), the Connecticut data were characterized by

1. Amplitude dips and relative-phase increases during the nighttime period of 0400 to 0800 GMT,

2. Smaller amplitude dips and relative-phase increases around the beginning of the sunrise transition period (SRTP), ~1000 to 1200 GMT, and

3. Amplitude peaks around the beginning of the daytime propagation period (~1400 to 1600).

Amplitude peak-to-trough variations of 4 to 5 dB occurred during most of the days, while the largest daily field-strength difference (6 dB) was measured on 6 January (-149.2 dBA/m at 0730 to -143.2 dBA/m at 1430). The average night-to-day relative-phase variation ($\Delta\phi$) was 17 ±6 deg (see table 3 in main text).

During the 17 to 27 January period (figures B-9 through B-19), the Connecticut data were characterized by rather severe phase fluctuations during nighttime and SRTP propagation conditions. The daily $\Delta\phi$ variation was 25 ±8 deg (see table 3 in main text), and the phase increased during part of the SRTP nearly every day from 18 to 26 January.

The largest amplitude peak-to-trough variations (5 to 6 dB) occurred on 18, 19, 23, and 24 January. It should be noted that the average predetection SNR (in a 1-Hz bandwidth) was -1 dB during this time period (17 to 27 January). The average postdetection SNR (after 30-min integration time) was 31.5 dB.

From 29 through 31 January, the WTF was operated at a phasing of 200 deg for 24 hr per day. The data taken during these three days (figures B-21 to B-23) were similar to the data taken during the first half of January (figures B-2 through B-8), except that the amplitude peak-to-trough variations were slightly larger (6 to 8 dB). In particular, the 30 January field strength versus time plot is very similar to the Connecticut nighttime data taken during 26 January and 20 March 1974.* (The peak-to-trough variation during these three nights was 6 to 8 dB, with the minimum field strength occurring around 0400 to 0800 GMT.)

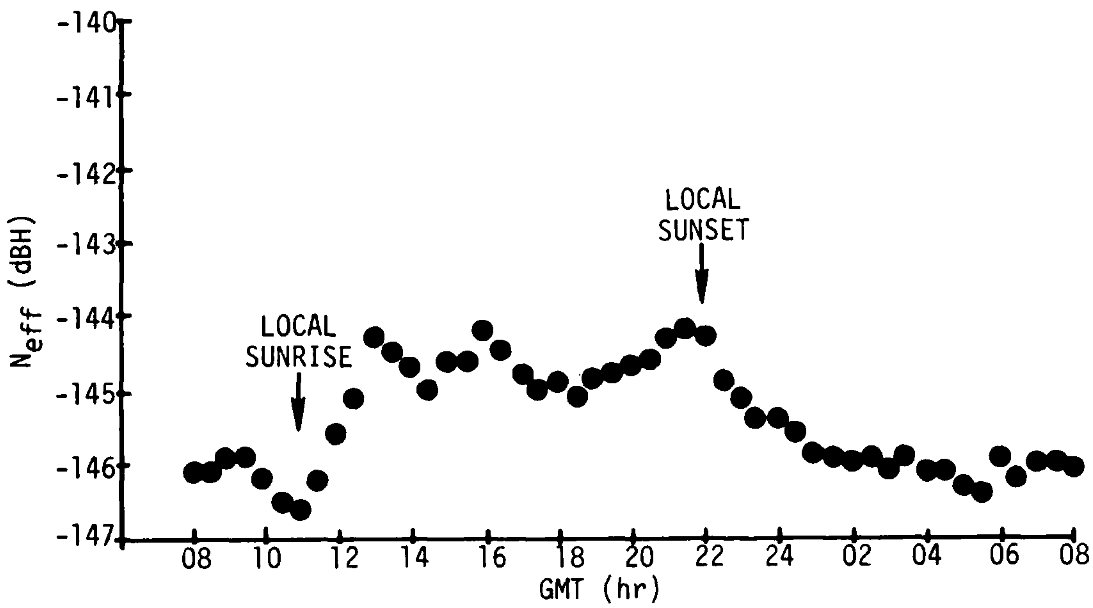

Figure B-1. Connecticut Average Effective-Noise Data Versus GMT, 17 to 27 January 1977

*P. R. Bannister, "Variations in Extremely Low Frequency Propagation Parameters," Journal of Atmospheric and Terrestrial Physics, vol. 37, no. 9, 1975, pp. 1203-1210.

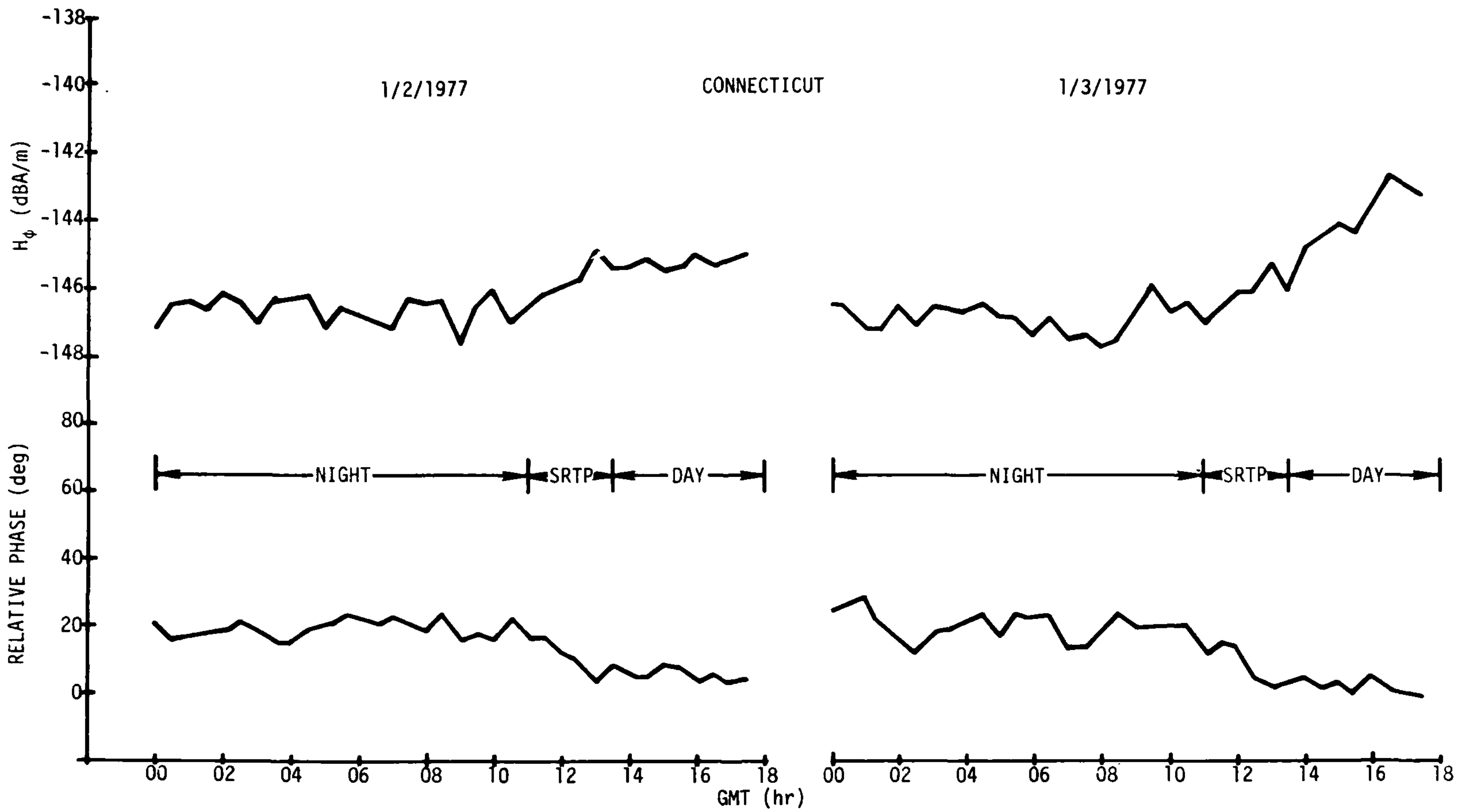

Figure B-2. Connecticut Field Strength Versus GMT, 2 and 3 January 1977

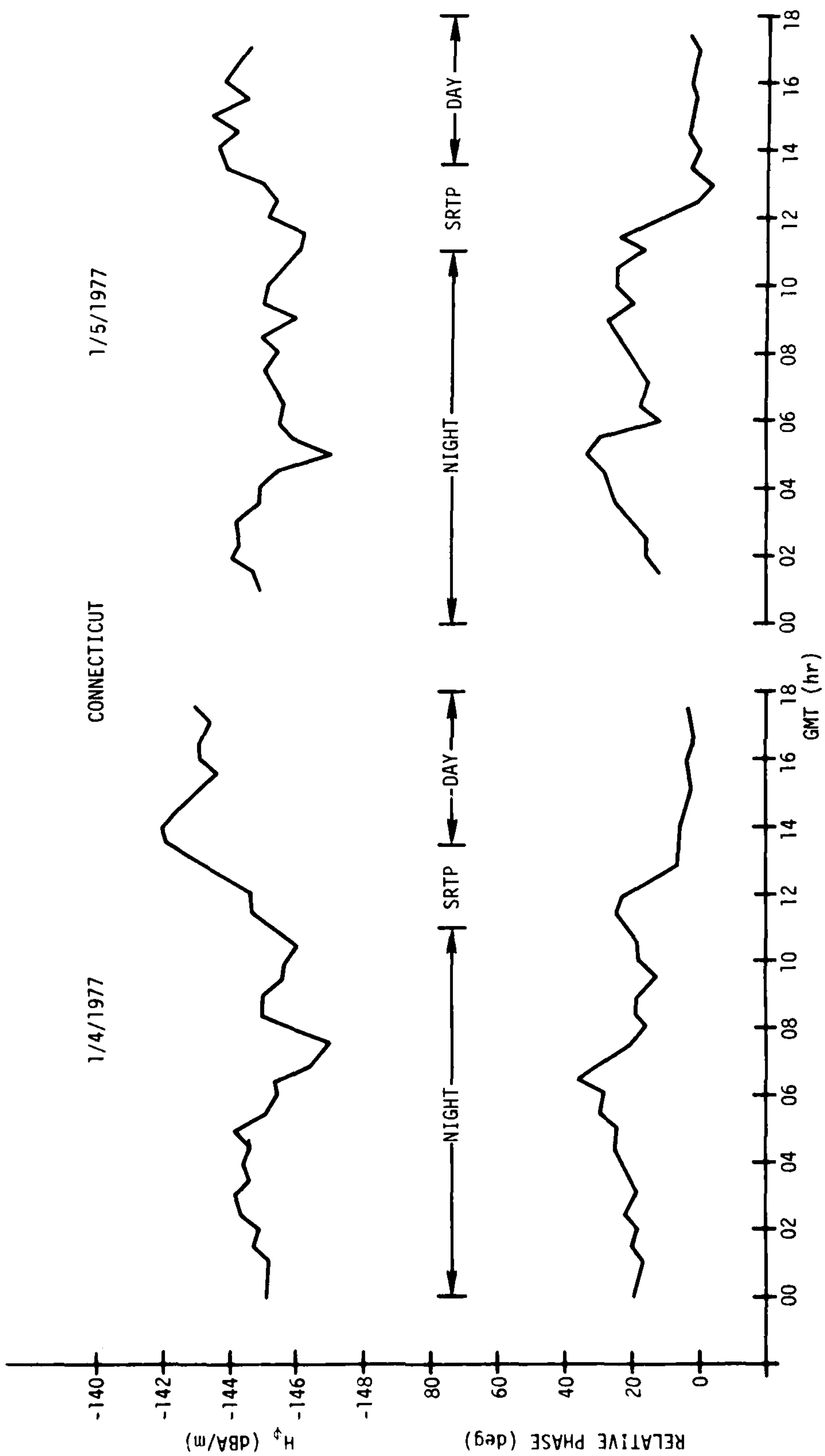

Figure B-3. Connecticut Field Strength Versus GMT, 4 and 5 January 1977

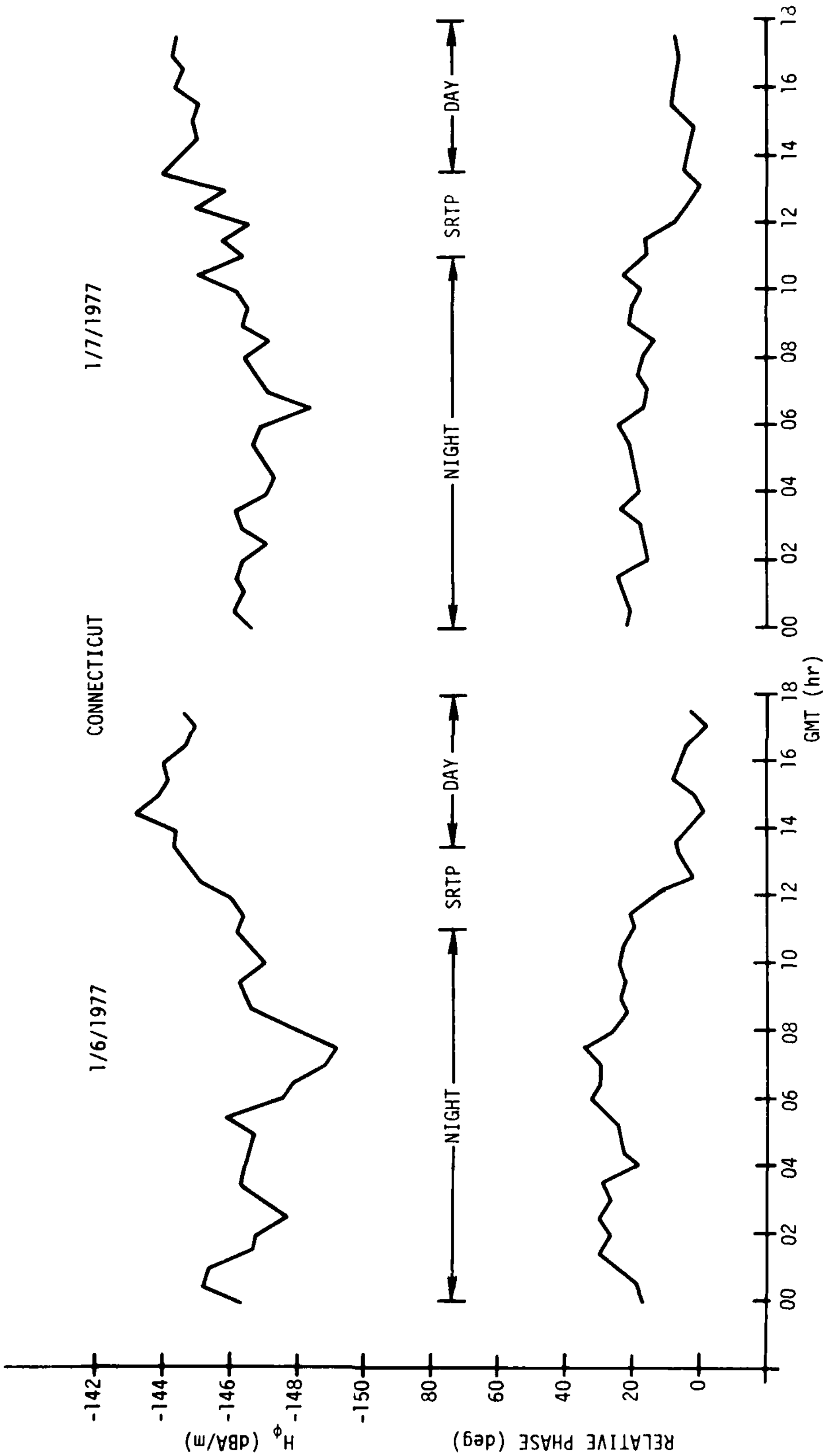

Figure B-4. Connecticut Field Strength Versus GMT, 6 and 7 January 1977

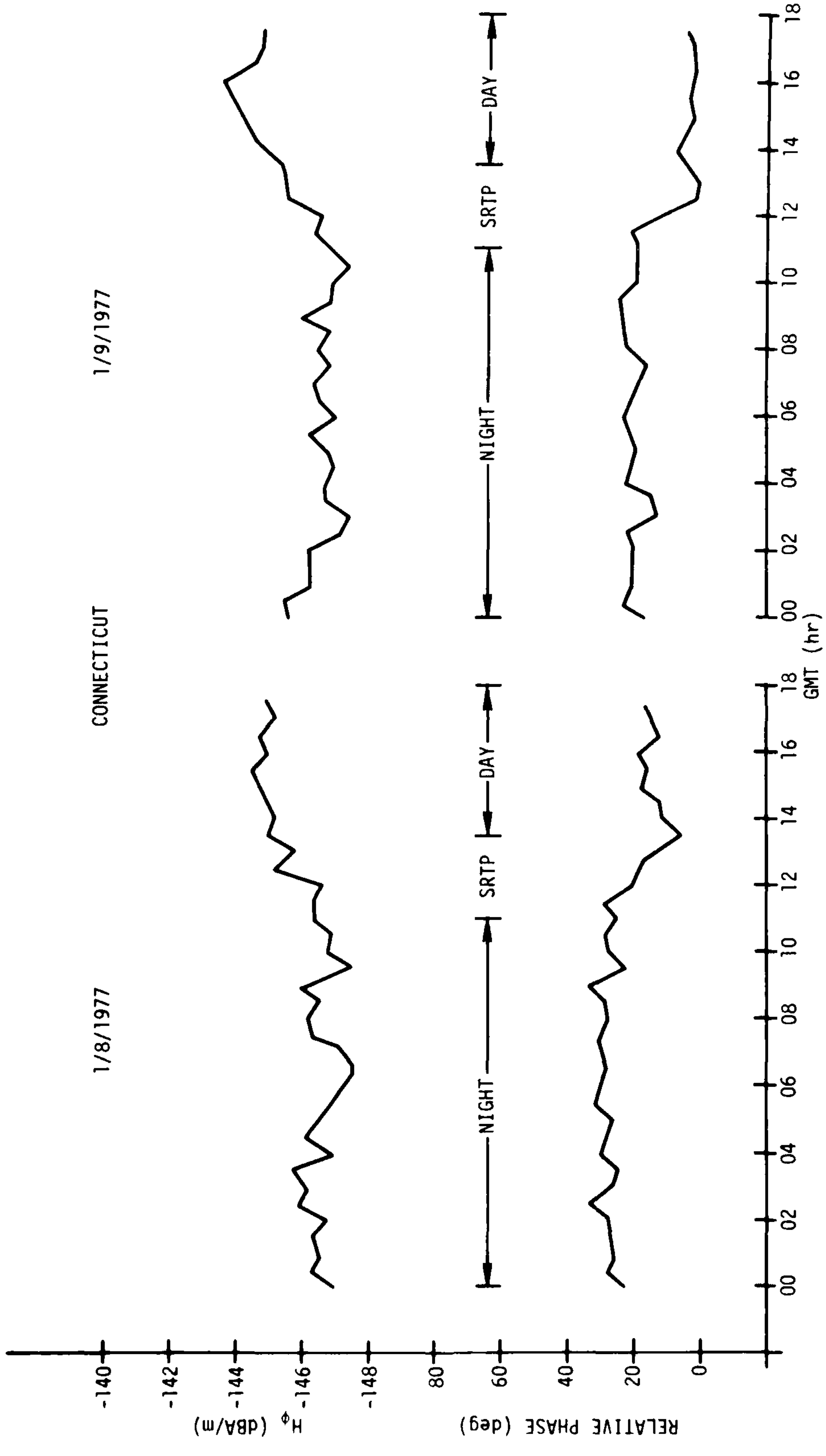

Figure B-5. Connecticut Field Strength Versus GMT, 8 and 9 January 1977

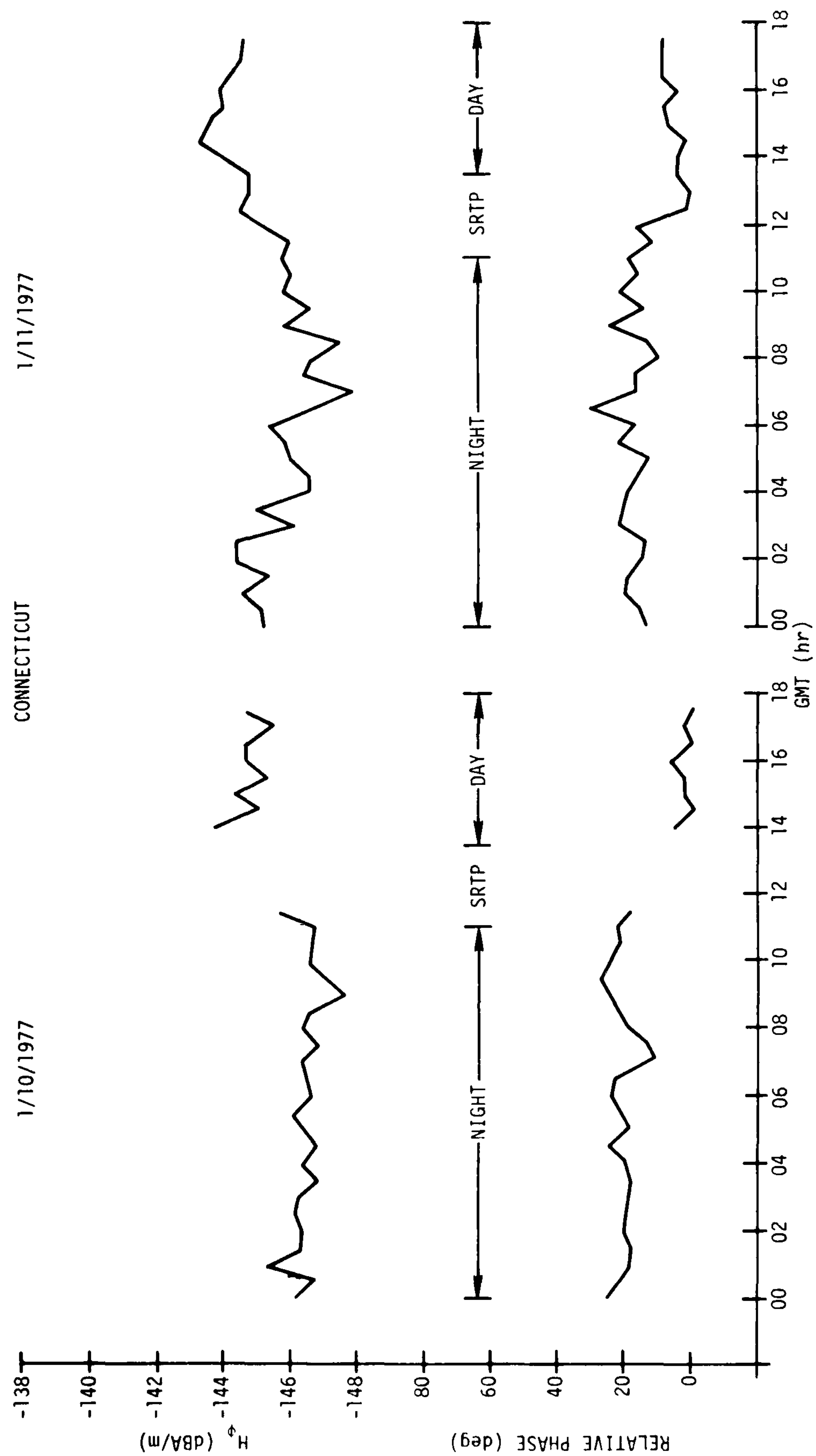

Figure B-6. Connecticut Field Strength Versus GMT,
10 and 11 January 1977

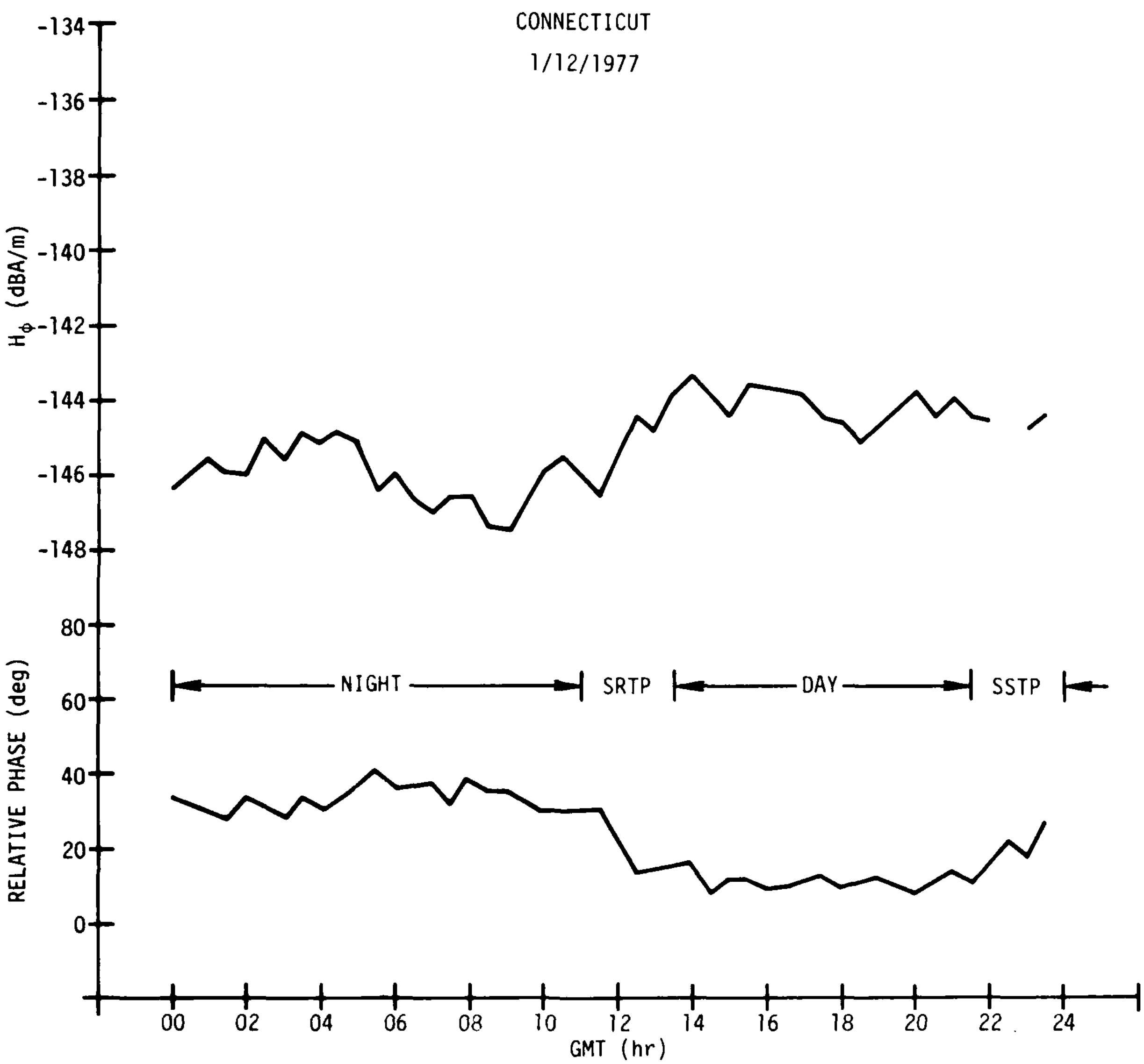

Figure B-7. Connecticut Field Strength Versus GMT, 12 January 1977

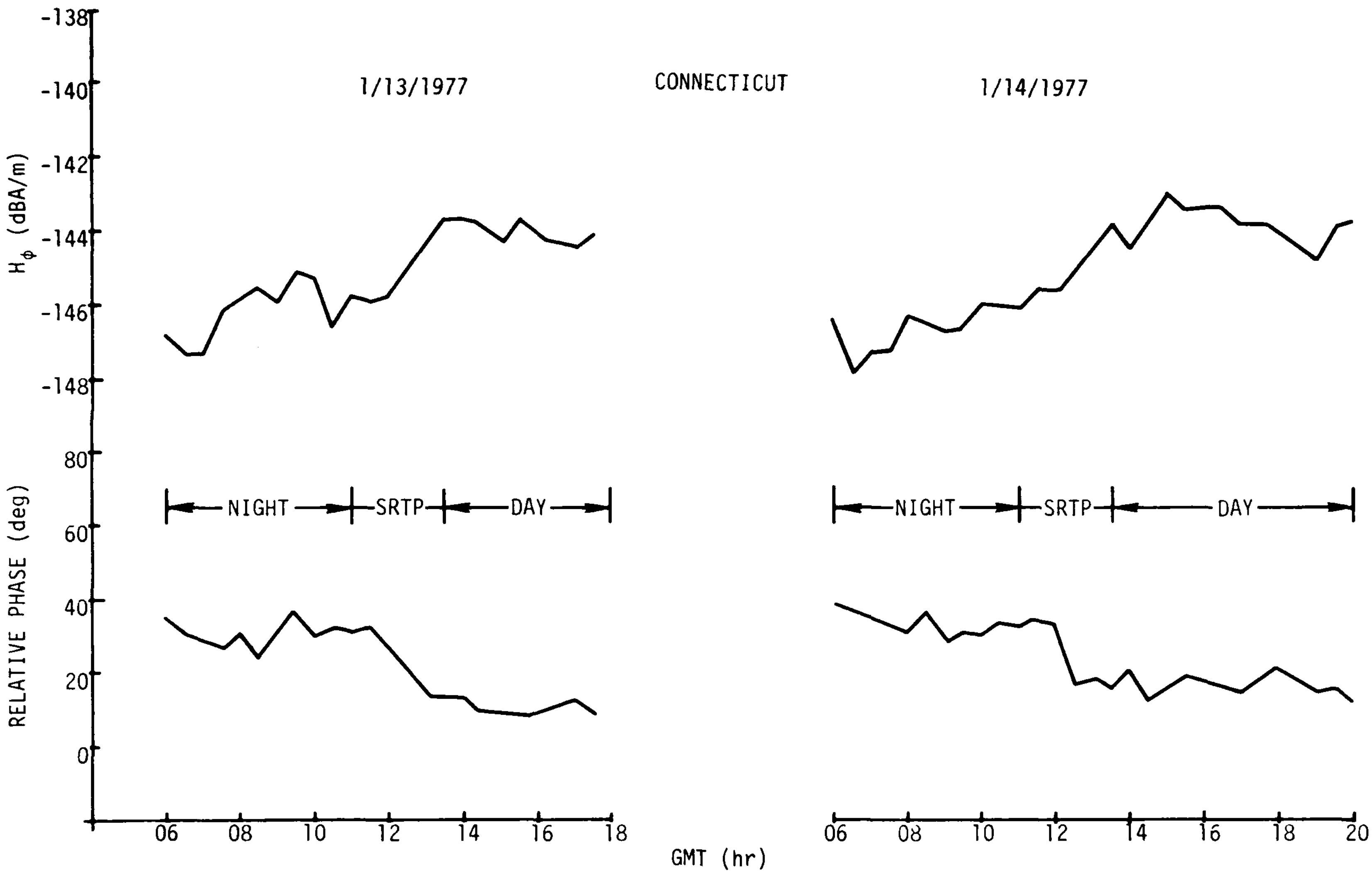

Figure B-8. Connecticut Field Strength Versus GMT, 13 and 14 January 1977

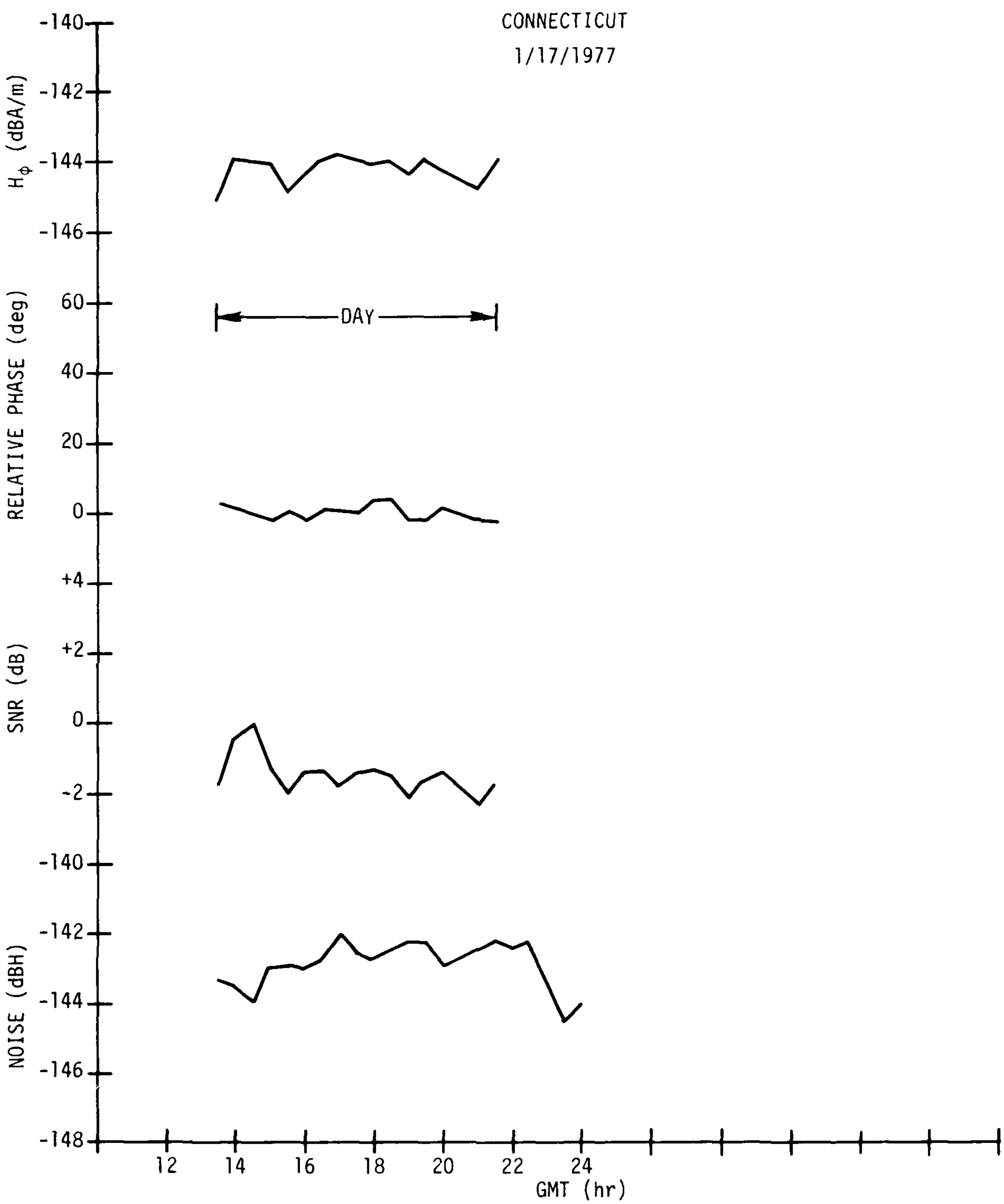

Figure B-9. Connecticut Field Strength Versus GMT, 17 January 1977

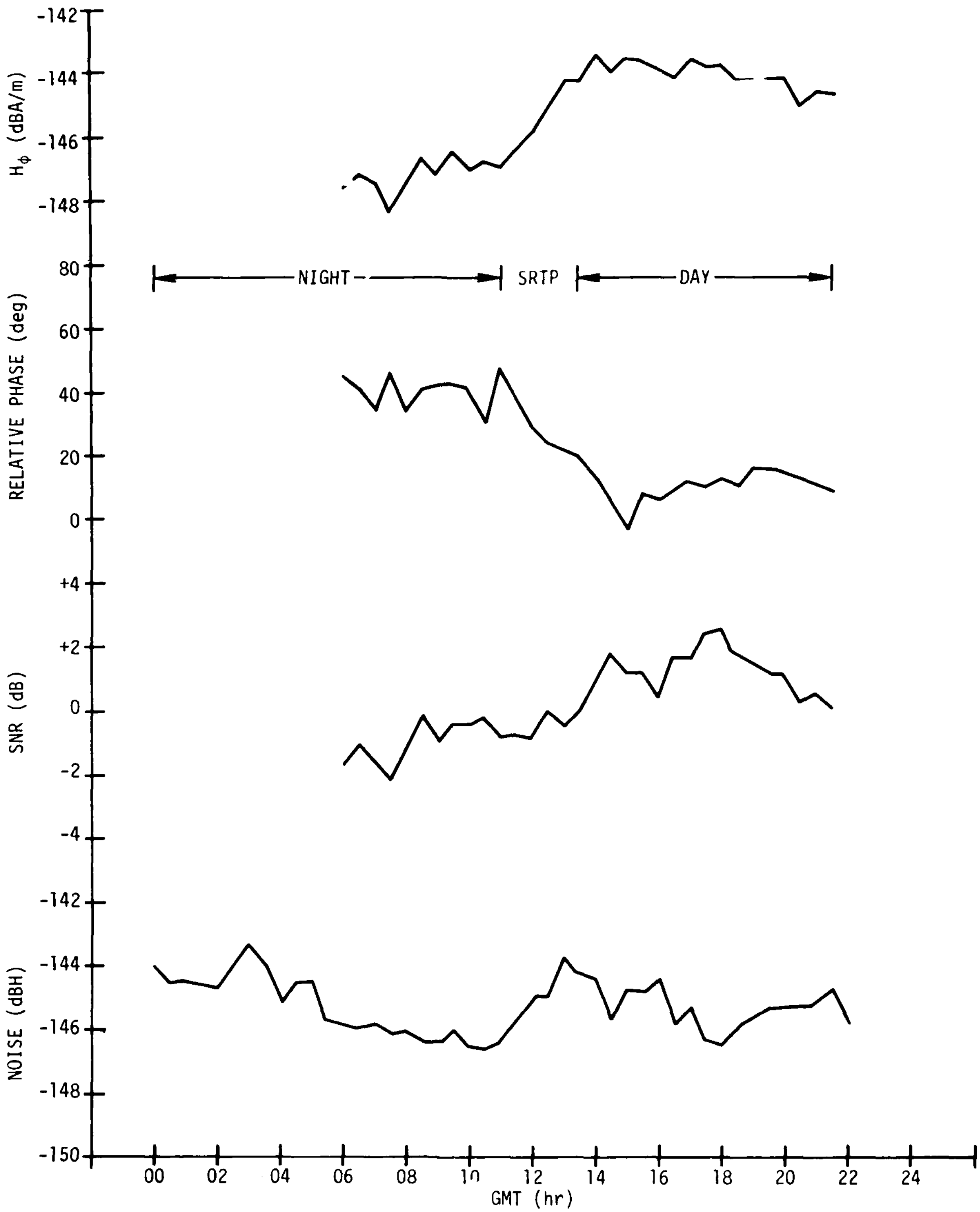

Figure B-10. Connecticut Field Strength Versus GMT, 18 January 1977

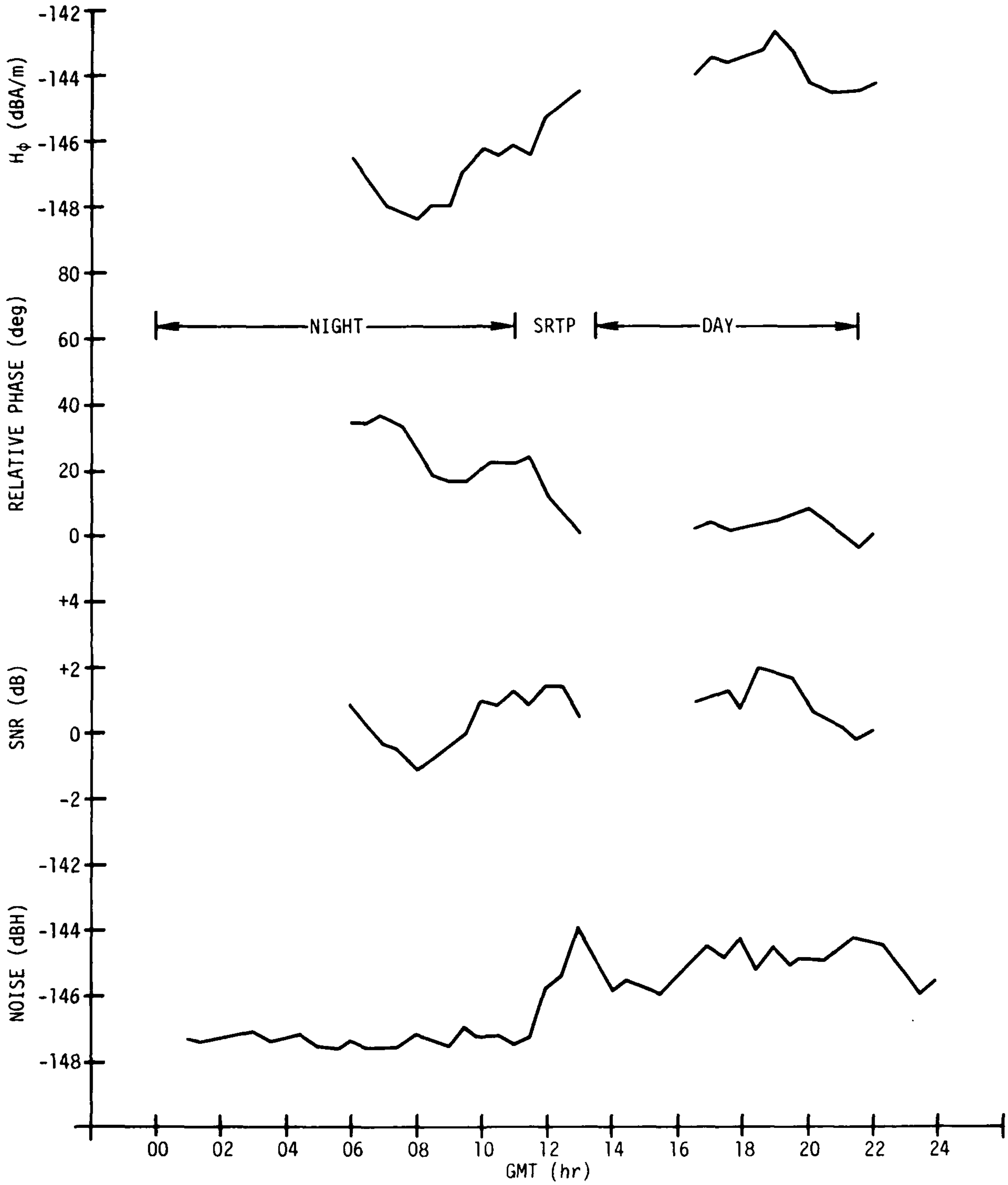

Figure B-11. Connecticut Field Strength Versus GMT, 19 January 1977

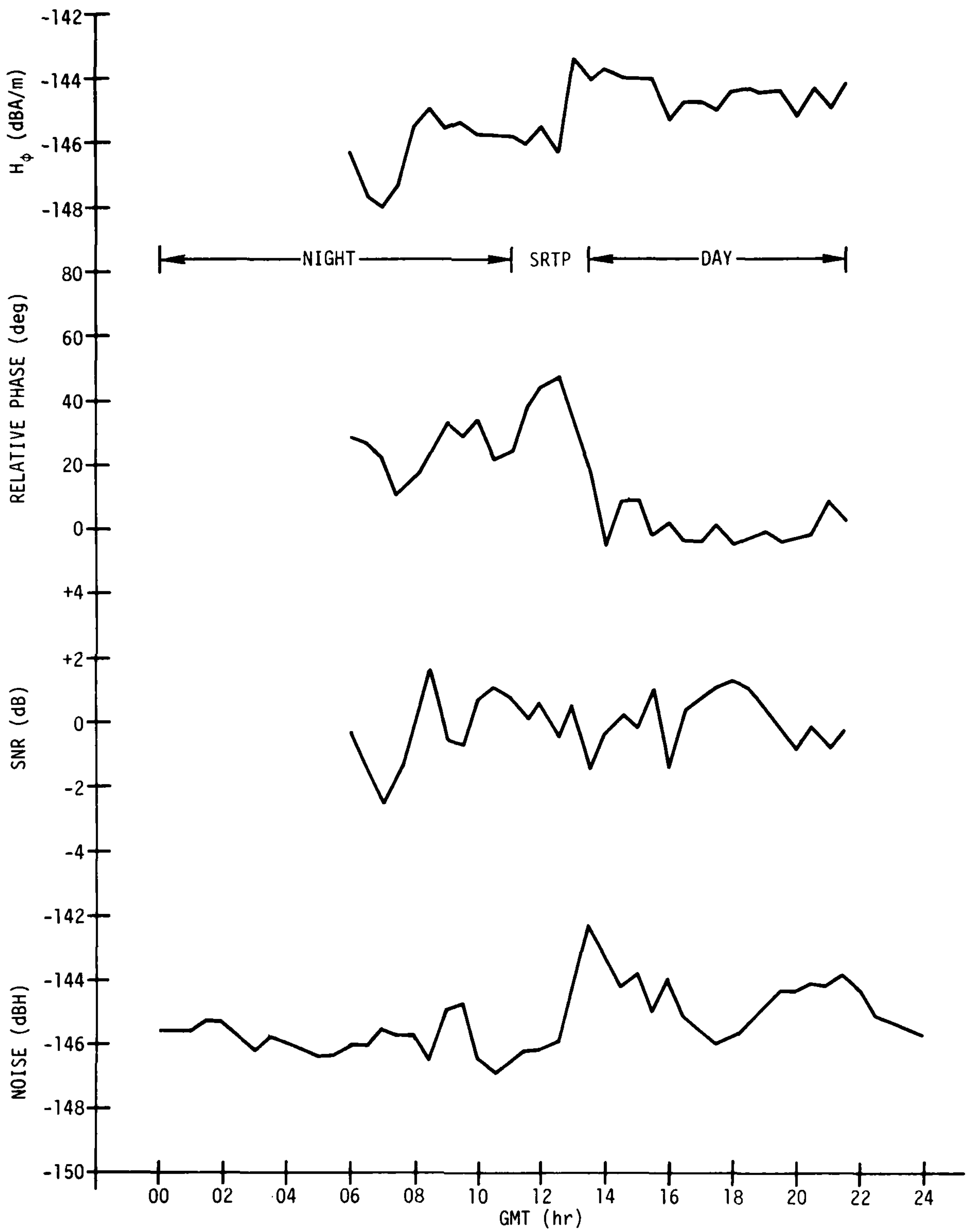

Figure B-12. Connecticut Field Strength Versus GMT, 20 January 1977

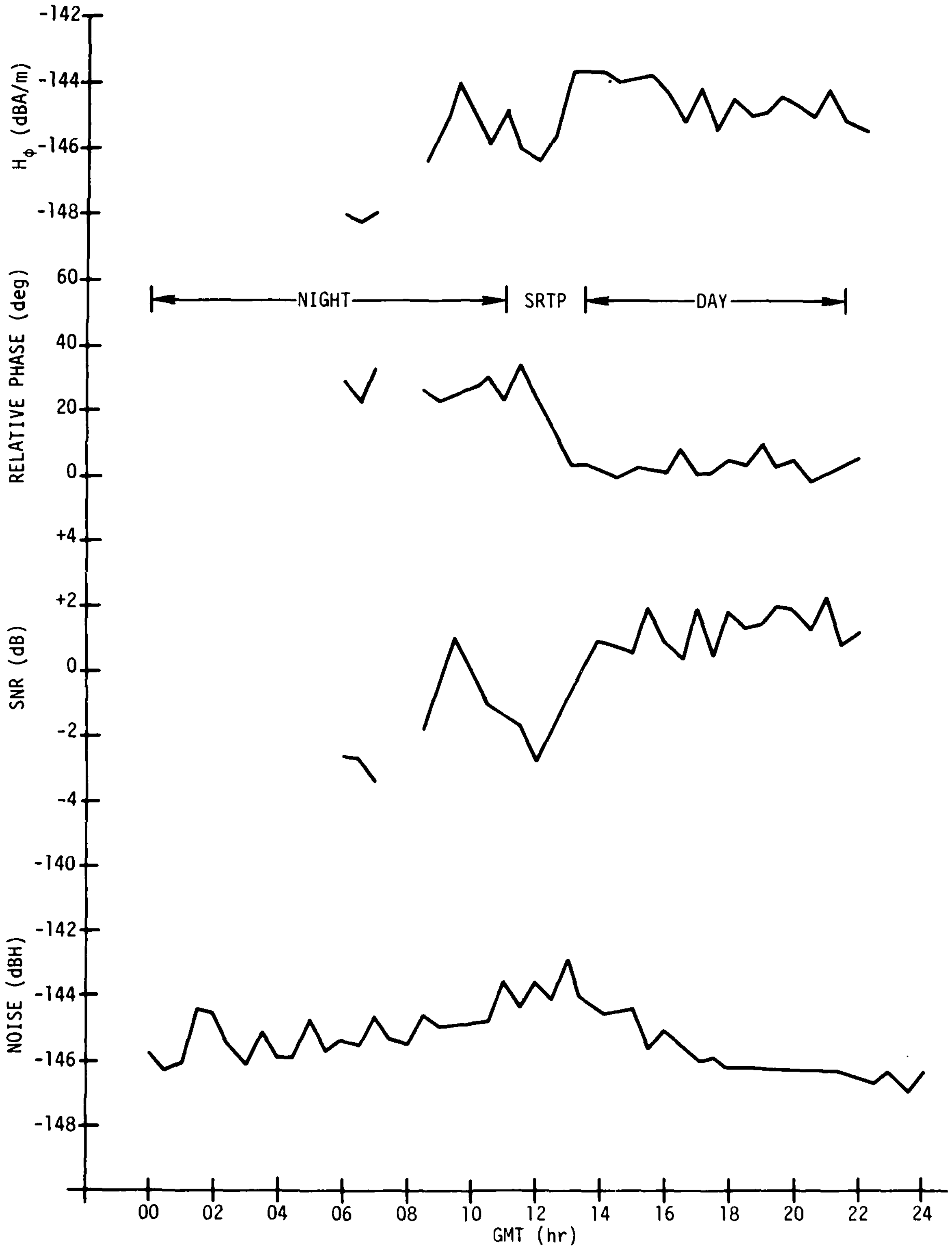

Figure B-13. Connecticut Field Strength Versus GMT, 21 January 1977

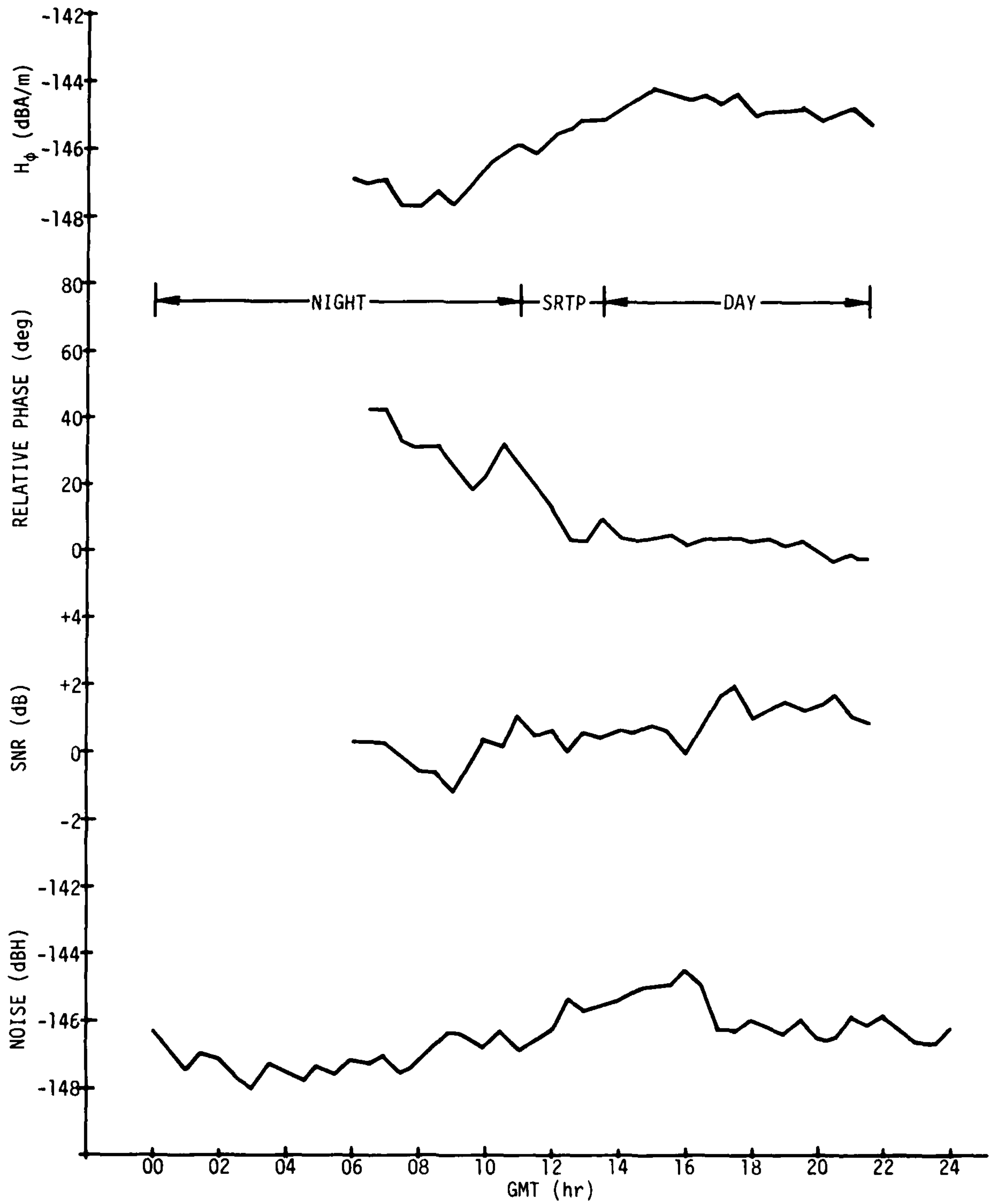

Figure B-14. Connecticut Field Strength Versus GMT, 22 January 1977

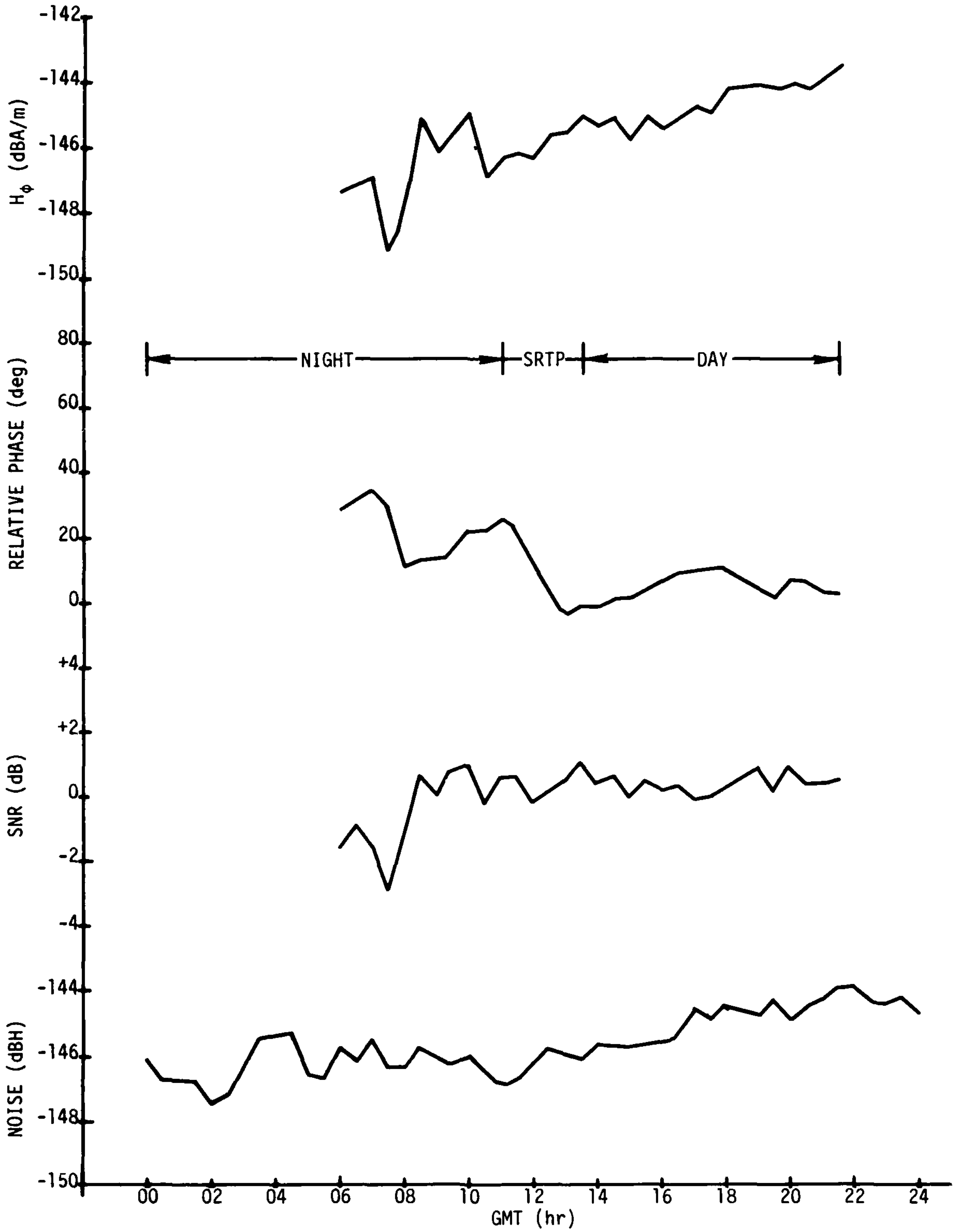

Figure B-15. Connecticut Field Strength Versus GMT, 23 January 1977

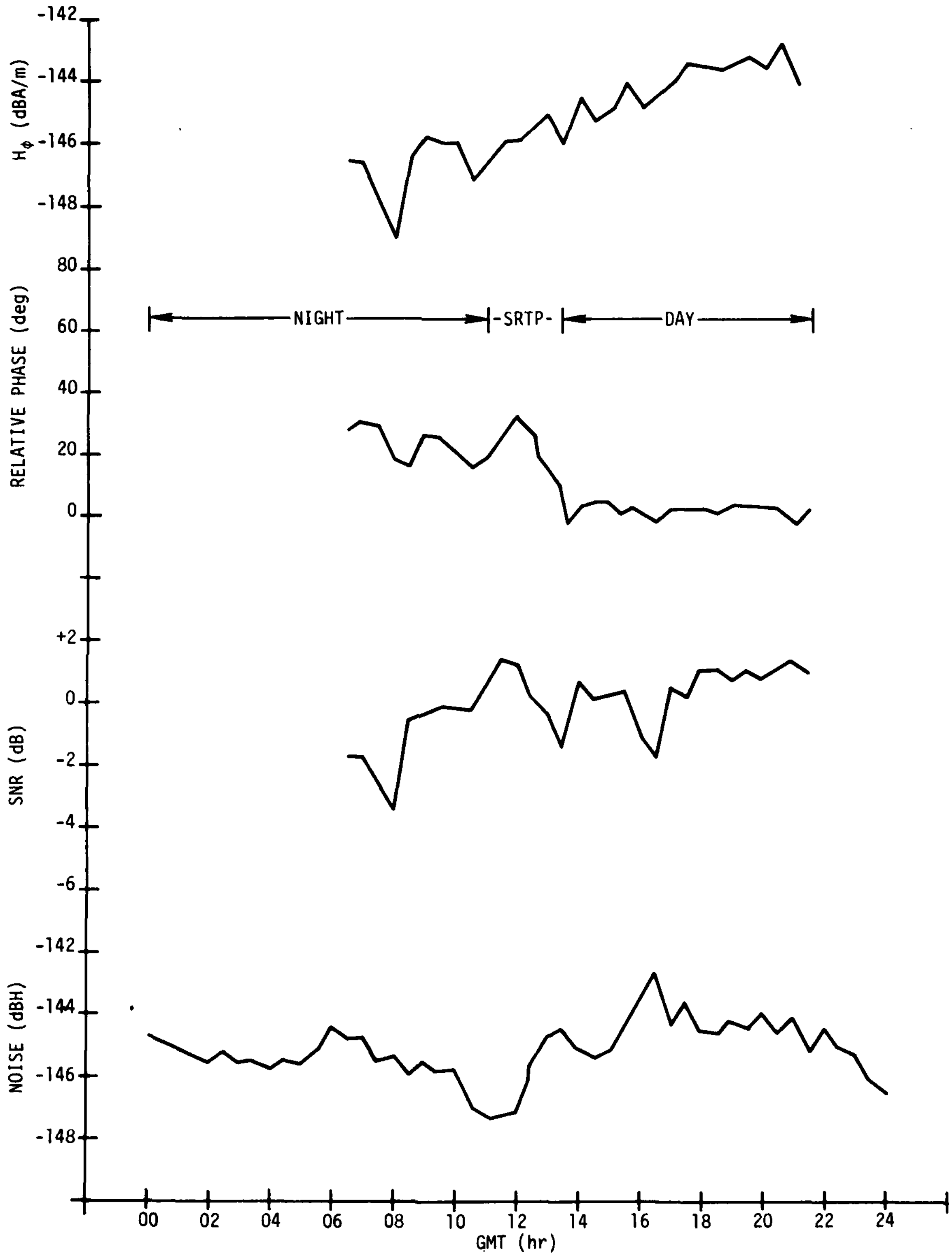

Figure B-16. Connecticut Field Strength Versus GMT, 24 January 1977

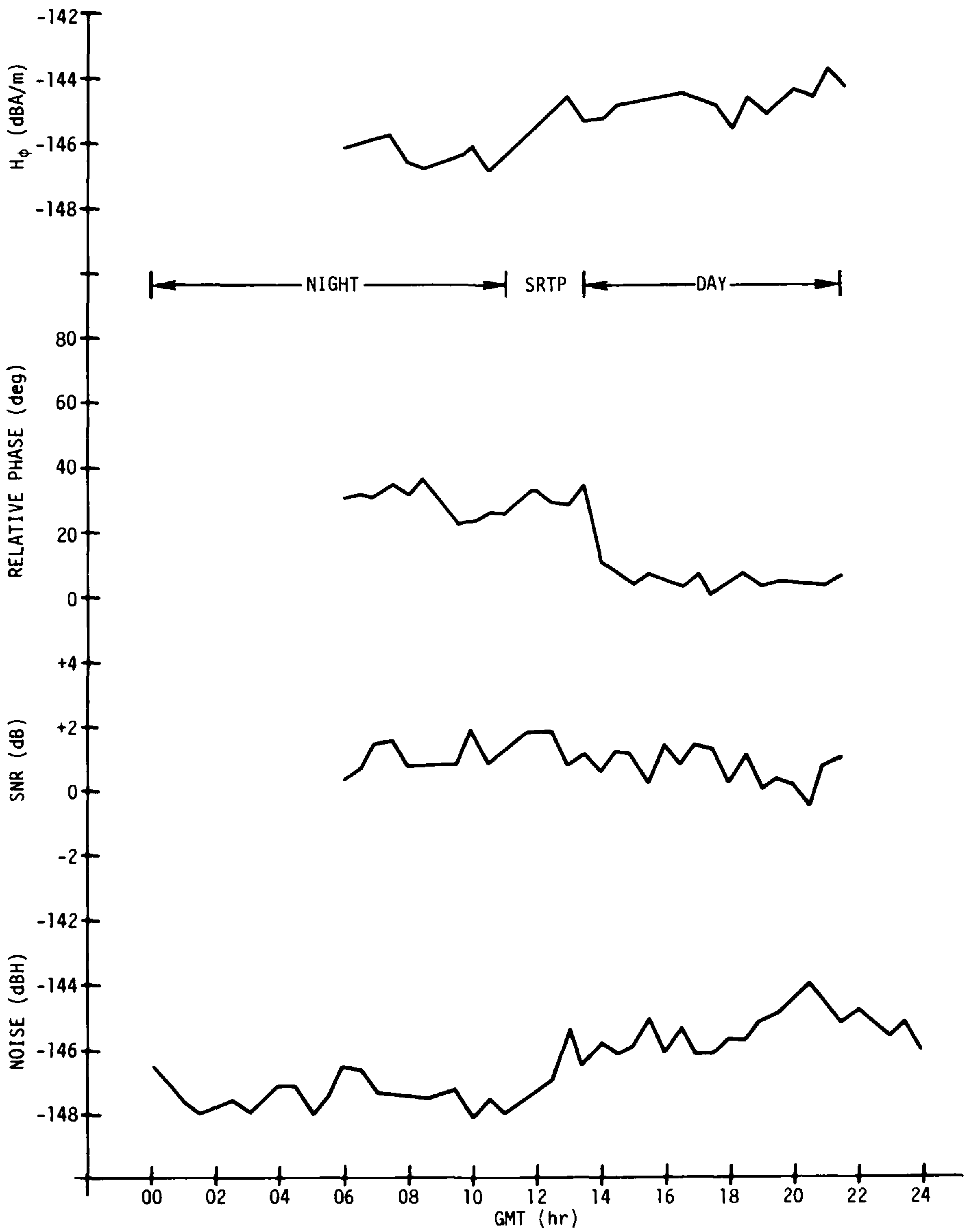

Figure B-17. Connecticut Field Strength Versus GMT, 25 January 1977

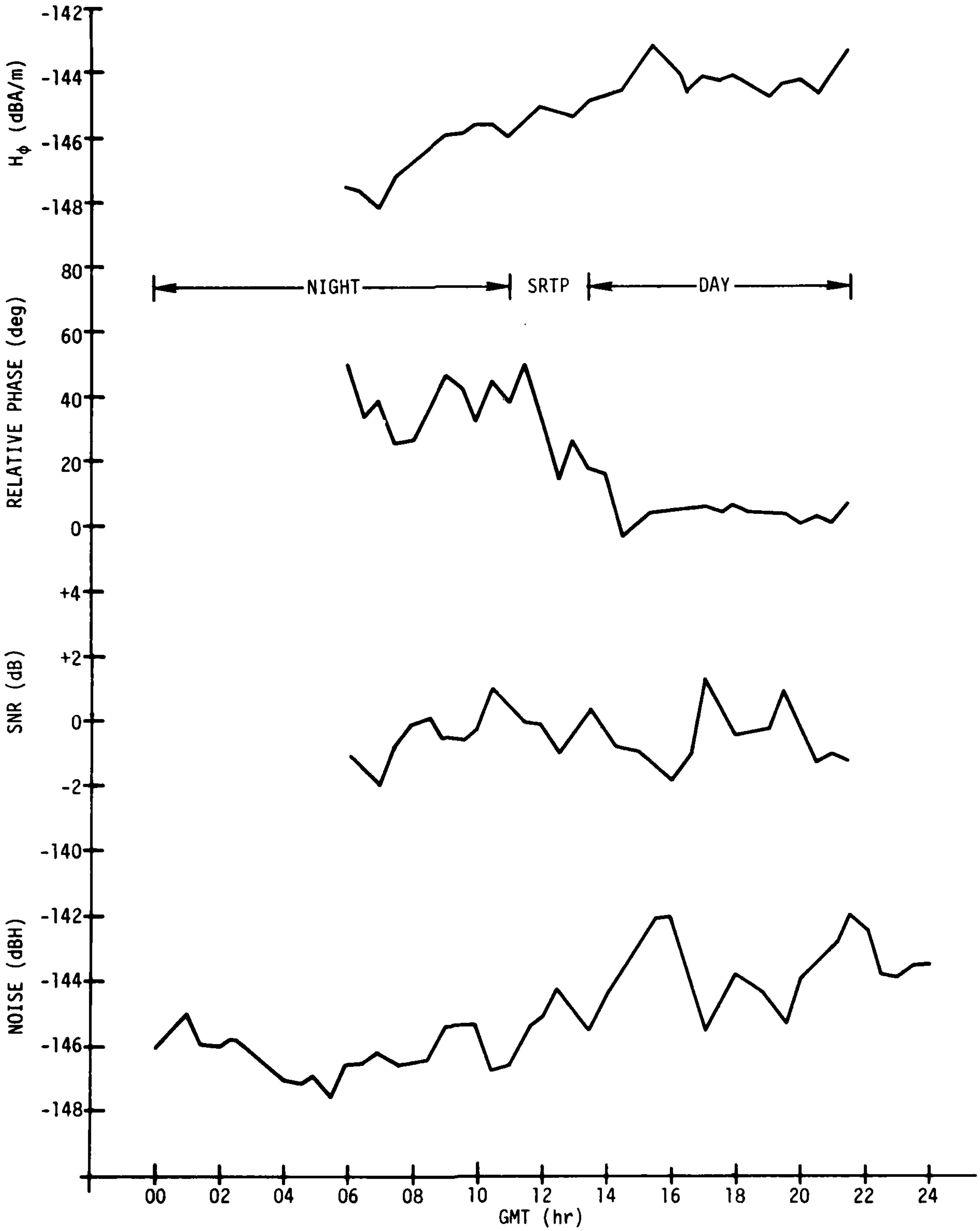

Figure B-18. Connecticut Field Strength Versus GMT, 26 January 1977

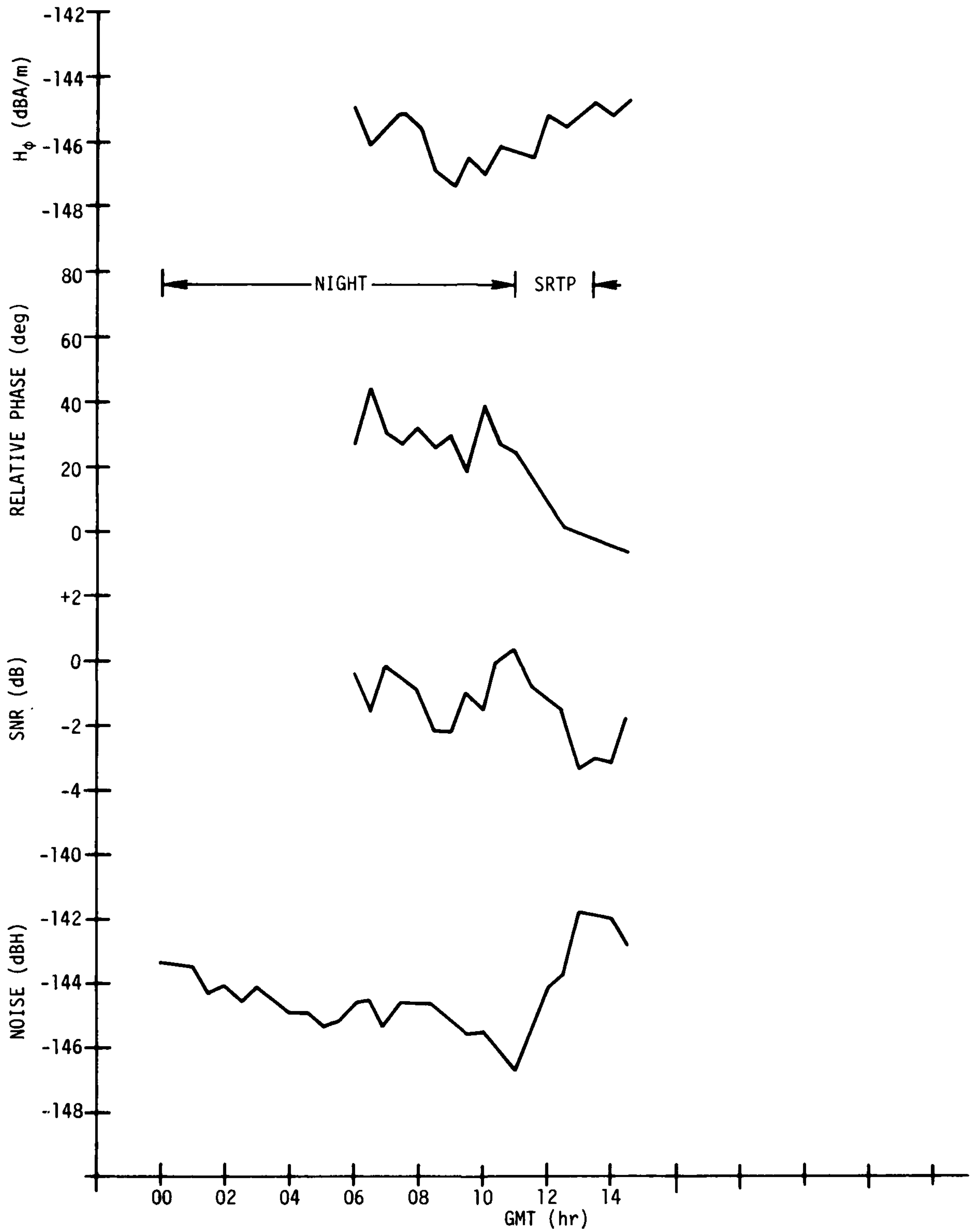

Figure B-19. Connecticut Field Strength Versus GMT, 27 January 1977

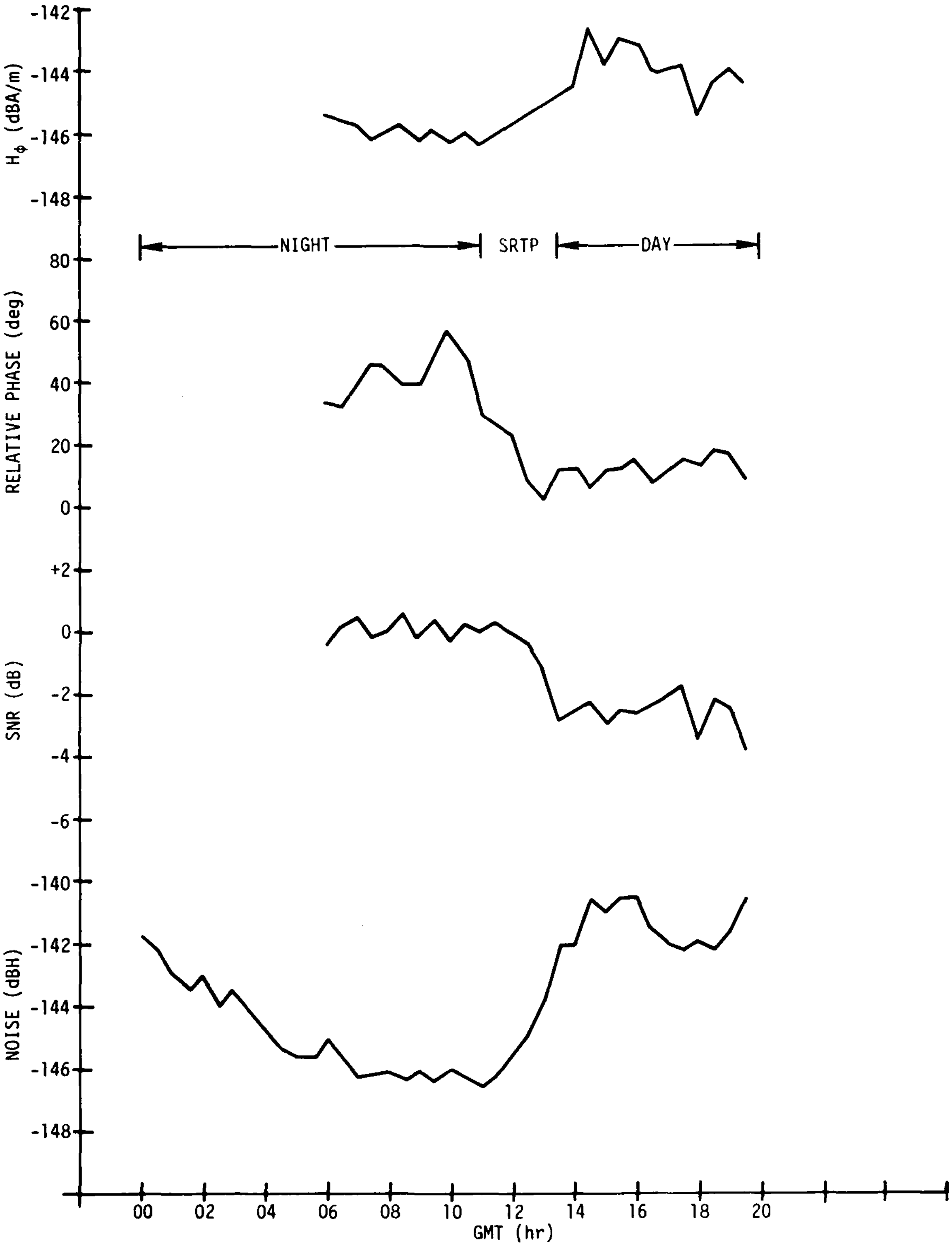

Figure B-20. Connecticut Field Strength Versus GMT, 28 January 1977

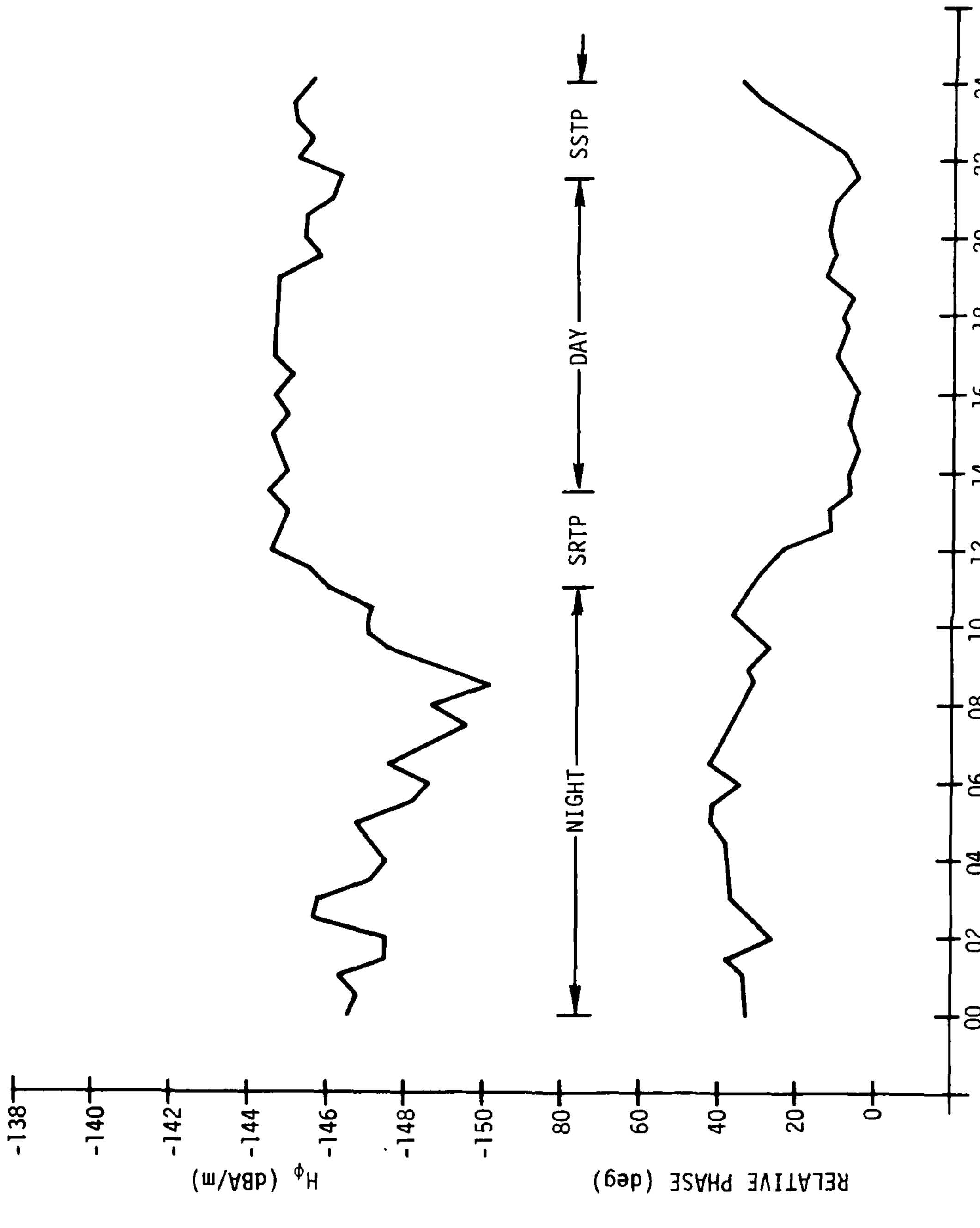

Figure B-21. Connecticut Field Strength Versus GMT (WTF Antenna Phasing = 200 deg), 29 January 1977

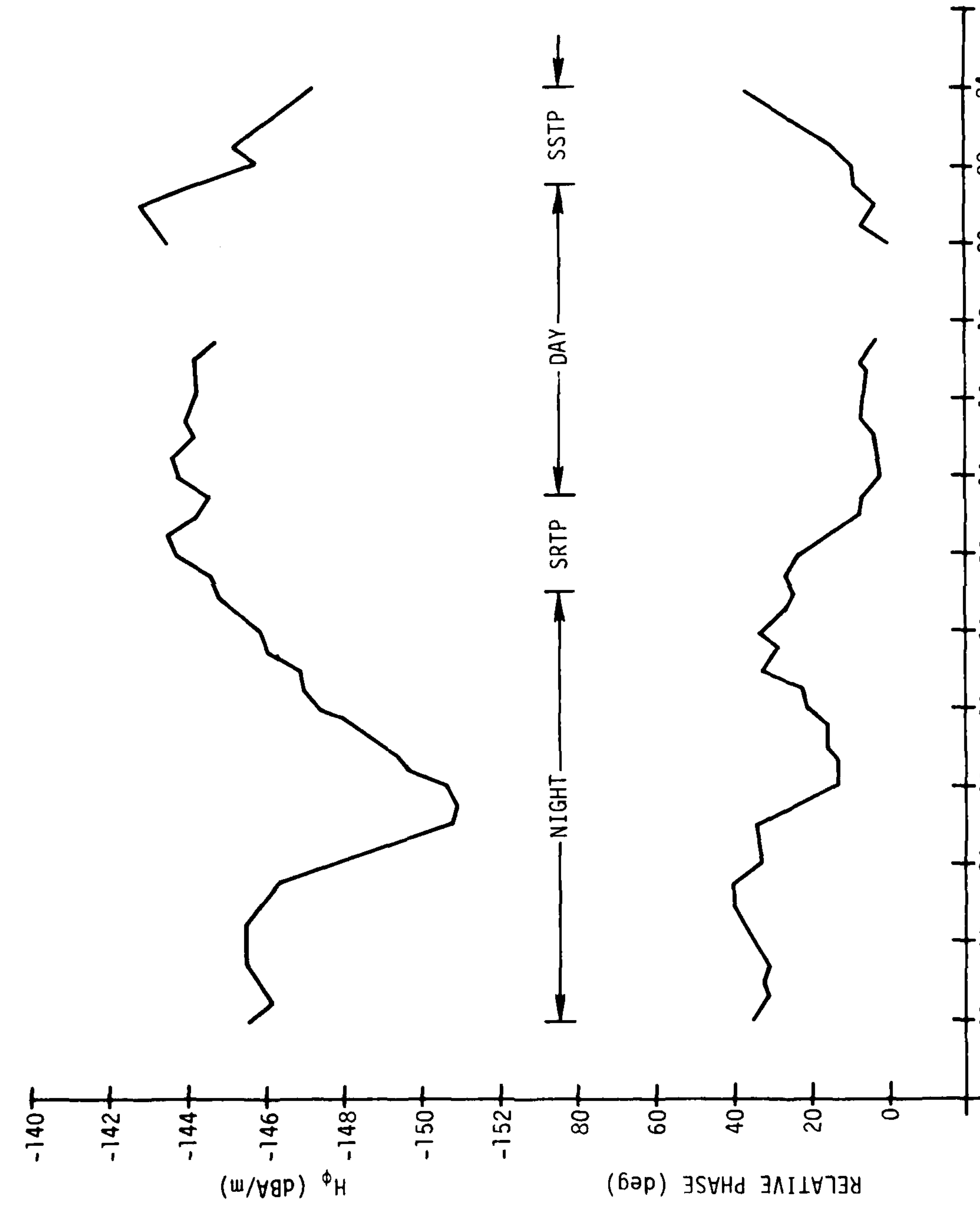

Figure B-22. Connecticut Field Strength Versus GMT (WTF Antenna Phasing = 200 deg), 30 January 1977

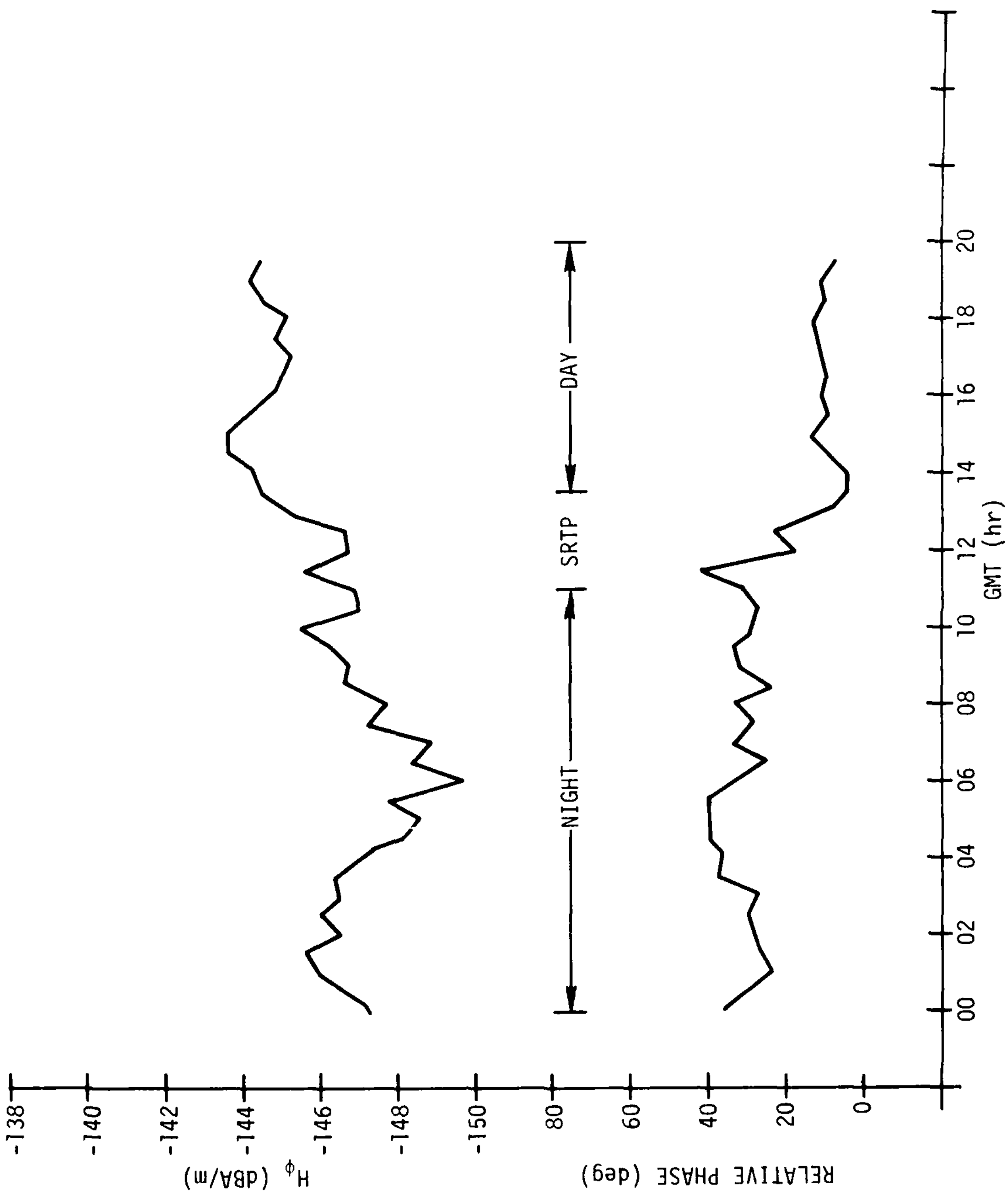

Figure B-23. Connecticut Field Strength Versus GMT (WTF Antenna Phasing = 200 deg), 31 January 1977

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